Proceedings of the Fifth Pacific Coast Herring Workshop, October 29-30, 1985

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Fisheries and Aquatic Sciences No. 1871

March 1986

PROCEEDINGS OF THE FIFTH PACIFIC COAST HERRING WORKSHOP, OCTOBER 29-30, 1985

by

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INTRODUCTION

Since the last herring workshop in Seattle in 1981 there have been substantial changes in the resource, in the way we have managed the fisheries, and some real progress in research. The recent El Niño appears to have affected herring growth and survival. The management of some of the fisheries has become more structured. Area licensing was introduced in B.C. in 1981 on a trial basis and retained and refined. Time of spawning, from pre-season sampling has been successfully predicted, and used to forecast the optimum time for harvesting herring for roe. New techniques for alternate harvesting are being developed. Impounding, where fish are caught for sac roe prior to full maturation and harvested at optimal ripeness, has been shown to be feasible. "Open" ponding for spawn-on-kelp products, where fish, in fact, are not impounded, but the kelp is suspended on rafts on spawning grounds has been successfully used in the Queen Charlotte Islands. There is work underway for culturing kelp for spawn-on-kelp production. There has been considerable progress in improving stock assesment models, by incorporating, for example, environmental information into mathematical models. Much of the spawn survey data base has been scrutinized and its quality improved by re-analysis and SCUBA surveys. There have been alternate stock strength indicators, such as hydroacoustic surveys and size-at-age, developed. The survival of eggs and larvae has been studied. The role of predators in affecting survival has been examined. There has been some progress in techniques of stock identification.

The results from some of these developments, plus many others, were presented at this workshop. The workshop was divided into five sessions and each session was led by a chairman. It was the intention to have a discussion at the end of each session to allow attendees an opportunity to contribute other than in a presentation. Unfortunately, there was insufficient time to accomplish this. In all there were 31 presentations and 49 attendees from four states, two provinces, five government organizations, five universities, and two private research firms. Since the herring workshops are informal meetings where some of the data and analysis are preliminary, authors should be contacted for confirmation before being cited.

Vidar Wespestad of the National Marine Fisheries Service at Sandpoint will, with help from staff in the Washington Department of Fisheries, organize the sixth Pacific coast herring workshop for 1988.

Carl Haegele
Pacific Biological Station
Workshop Organizer and Chairman

INTRODUCTION

Depuis le dernier atelier sur le hareng qui a eu lieu à Seattle en 1981, des changements importants sont survenus au niveau de la ressource, dans la façon dont nous avons gérê les pêches et il y a eu certains progrès réels dans la recherche. Le courant El Nino semble avoir influé sur la croissance et la survie des harengs. La gestion de certaines pêches est devenue plus structurée. On a introduit à titre d'essai en 1981 en C.-B. la délivrance de permis de pêche par secteur, système qu'on a retenu par après puis amélioré. On a prédit avec succès le moment de la fraye à partir d'un échantillonnage effectué avant la saison de pêche et on s'en est servi pour prévoir le meilleur moment pour récolter les oeufs de hareng. On a mis au point de nouvelles techniques pour une pêche alternative. On a montré que la mise en captivité, technique où on capture les poissons pour leurs oeufs avant qu'ils ne soient complètement matures et où on les récolte quand le développement est optimal, est faisable. Dans les îles Reine-Charlotte, on a eu recours avec succès à des étangs "ouverts" pour les oeufs sur varech, où les poissons en réalité n'étaient pas mis en captivité, mais où le varech était suspendu sur des radeaux sur les lieux de fraie. Des travaux sont en cours pour cultiver du varech en vue de la production d'oeufs sur varech. Des progrès considérables ont été faits pour améliorer les modèles d'évaluation des stocks, en introduisant par exemple dans les modèles mathématiques des informations environnementales. On a examiné avec soin une bonne partie de la base des données fournies par les levés sur la ponte et on a amélioré sa qualité en effectuant une nouvelle analyse et des levés en scaphandre autonome. On a établi d'autres indicateurs de l'importance des stocks, tels que les levés hydroacoustiques et la taille par âge. On a étudié la survie des oeufs et des larves. On a examiné le rôle joué par les prédateurs dans la survie. Il y a eu certains progrès réalisés dans les techniques d'identification des stocks.

Les résultats de certaines de ces réalisations ainsi que beaucoup d'autres ont été présentés au cours de cet atelier. On a divisé l'atelier en cinq séances et chaque séance était dirigée par un président. Une discussion était prévue à la fin de chaque séance pour donner aux participants l'occasion de contribuer autrement qu'en faisant un exposé. Malheureusement, le temps a manqué pour ce faire. Il y a eu en tout 31 exposés et 49 participants venant de quatre États, de deux provinces, de cinq organismes gouvernementaux, de cinq universités et de deux établissements privés de recherches. Étant donné que les ateliers sur le hareng sont des réunions non officielles où certaines des données et des analyses sont préliminaires, on doit communiquer avec les auteurs pour avoir une confirmation avant de les citer.

Vidar Wespestad du National Marine Fisheries Service à Sandpoint organisera, avec l'aide du personnel du Department of Fisheries de Washington, le sixième atelier sur le hareng de la côte du Pacifique pour 1988.

Carl Haegele
Station de biologie du Pacifique
Organisatur et président de l'atelier

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FIFTH PACIFIC COAST HERRING WORKSHOP
SHERATON LANDMARK - VANCOUVER, OCTOBER 29-30, 1985

AGENDA

Tuesday, Oct. 29

0800 to 0845 - Registration
0845 to 0900 - Introduction - Carl Haegele, P.B.S., Nanaimo.

Session 1 - Management of Fisheries
Chairman - Dennis Chalmers, D.F.O., F.S.B., Nanaimo.

0900 to 0920 - Management of the herring fishery in B.C.
Sue Farlinger, D.F.O., F.S.B., Prince Rupert.

0920 to 0940 - A herring fishery manager's requirements for biological information.
Rob Wilson, D.F.O., F.S.B., Prince Rupert.

0940 to 1000 - Fisheries management and research in the Bering Sea.
Jeff Skrade, A.D.F.G., Dillingham.

1000 to 1020 - Coffee.

1020 to 1040 - Evaluation of the area licensing program.
Paul Macgillivray, D.F.O., Vancouver.

1040 to 1100 - Alternative management strategies for B.C. herring.
Don Hall, U.B.C., Vancouver.

1100 to 1120 - The spawn-on-kelp fishery in Alaska.
Richard Randall, A.D.F.G., Cordova.

1120 to 1140 - Progress in sac-roe impoundment research and options for management.
Henrik Kreiberg, P.B.S., Nanaimo.

1140 to 1200 - Discussion.

1200 to 1300 - Lunch.

Session 2 - Stock status and life history
Chairman - Vivian Haist, P.B.S., Nanaimo.

1300 to 1320 - A preliminary evaluation of an Arctic herring stock.
Alan Kristofferson, D.F.O., Winnipeg.

1320 to 1340 - Stock trends in B.C. herring.
Vivian Haist, P.B.S., Nanaimo.

1340 to 1400 - Status of herring stocks in Puget Sound.
Dan Penttila, W.D.F., Seattle.

1400 to 1420 - Age and growth of herring in San Francisco Bay.
Paul Reilly, C.D.F.G., Menlo Park.

1420 to 1440 - Early life history of herring in Puget Sound.
Dan Penttila, W.D.F., Seattle.

1440 to 1500 - Nearshore distribution and growth of larval herring near Birch Point.
Tom Keegan, U. of WA., Seattle.

1500 to 1520 - Discussion.

1520 to 1540 - Coffee.

Session 3 - Special problems and techniques.
Chairman - Doug Hay, P.B.S., Nanaimo.

1540 to 1600 - Uptake and depuration of hydrocarbons into gonads of herring.
Chris Broderson, N.M.F.S., Auke Bay.

1600 to 1620 - Induced maturation of herring by LHRH implants.
Joachim Carolsfeld, U. of VIC., Victoria.

1620 to 1640 - Observed recovery rates for anchor tags in B.C. herring fisheries.
Carl Haegele, P.B.S., Nanaimo.

1640 to 1700 - Hydroacoustic "stepping-down" technique to estimate herring density.
Robert Armstrong, D.F.O., F.S.B., Nanaimo.

1700 to 1720 - Discussion.

Wednesday, Oct. 30.

Session 4 - Recruitment
Chairman - Max Stocker, P.B.S., Nanaimo.

0830 to 0850 - The influence of winter sea temperatures on reproductive characteristics.
Ron Tanasichuk, P.B.S., Nanaimo.

0850 to 0910 - Analysis of the effect of climatic variability on year-class strength in the east Bering Sea.
Vidar Wespestad, N..M.F.S., Seattle.

0910 to 0930 - Between-year variability in growth and reproduction of Washington's Strait of Georgia herring.
Peter Dygert, U. of WA., Seattle.

0950 to 1010 - Compensatory mortality in Pacific herring eggs.
Wayne Palsson, W.D.F., Olympia.

1010 to 1030 - Coffee.

1030 to 1050 - Developing herring embryos exposed to oil in seawater.
Michael Stekoll, U. of Alaska, Juneau.

1050 to 1110 - Jellyfish predation on larval herring at spawning grounds in B.C.
Jennifer Purcell, Oregon State U., Corvallis.

1110 to 1130 - Egg loss in British Columbia herring spawns.
Carl Haegele, P.B.S., Nanaimo.

1130 to 1200 - Discussion.

1200 to 1300 - Lunch.

Session 5 - Stock identification
Chairman - Sue Farlinger, D.F.O., F.S.B., Prince Rupert.

1300 to 1320 - A stock hypothesis based on spawn and winter distribution.
Doug Hay, P.B.S., Nanaimo.

1320 to 1340 - Comparison of three stock separation procedures.
Jake Schweigert, P.B.S., Nanaimo.

1340 to 1400 - Scale analysis to discriminate herring stocks.
Dwane Day, W.D.F., Seattle.

1400 to 1420 - Tagging of Washington herring, 1936 to 1984.
Kurt Buchanan, W.D.F., Seattle.

1420 to 1440 - Discussion.

1440 to 1500 - Coffee.

Workshop Summary
1500 to 1520 - Vidar Wespestad and Max Stocker.

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SESSION 1

MANAGEMENT OF FISHERIES

Herring Management in British Columbia

S. Farlinger
Fisheries and Oceans
Prince Rupert, B.C.

INTRODUCTION

The herring fishery in British Columbia is based on the harvest of a fixed quota of 20% of the forecast run. Fundamental to this system are: a stock assessment consistent with all available information; and, a management structure to plan and implement the fishery consistently in all major areas. The dissemination of necessary information to and shared responsibility of those involved in every aspect of the fishery are vital in managing the fixed quota. Another key component is flexibility. These objectives are effected through the Herring Stock Assessment Committee, the Herring Working Group, the Herring Industry Advisory Board and the field management team.

HISTORY

Difficulties which have existed in the management of this fishery have largely been related to lack of communication and understanding between field staff, managers and researchers responsible for stock assessment. This confusion was exacerbated by pressure in-season on field officers to fish on stocks based on researchers' assessments which were not always confirmed by hydroacoustic estimates.

The fixed quota determined pre-season and area specific licensing obviated the latter difficulty; the isolation of management groups was a greater problem and was addressed by the formation of the three herring groups. Meetings between researchers and senior management had been part of the planning process; but the formalizing of these groups in 1982 with their more diverse representation and the greater involvement of the herring coordinator marked the beginning of the system developed to date.

STRUCTURE

The individuals comprising the Stock Assessment Committee (S.A.C.), Herring Working Group (H.W.G.), and Herring Industry Advisory Board (H.I.A.B.) come from sectors each with its own area of responsibility and interest (Fig. 1). Fishery Officers, district staff, management and research biologists and industry representatives participate in the process overseen by the Herring Coordinator (Fig. 2). The Herring Coordinator is responsible for organizing the process; he must be knowledgeable about every aspect of the

fishery, credible to industry and able to maximize the talents of management staff. It is the consensus from these many perspectives along with the responsibility of each group for its task which are the backbone of the management system.

During and after the herring fishery each year, herring spawn assessments are done by field officers. Lengths, widths of spawn, vegetation type and other variables are recorded and sent to the research biologists. This, and age structure and size information collected in the test and commercial fisheries, are used in the analytical stock assessment.

The research biologists use the information to produce two estimates of stock size: one based directly on spawn (Escapement Method) and one on a spawn index and age structure (Age Structure Model) (Fig. 3). Better analytical methods and more rigorously standardized data collection have led to greater confidence in the stock estimate. The results of these analyses are brought to the S.A.C. Relative stock strength trends in biological characteristics and field observations are used here by researchers, district staff and management biologists to determine the harvestable surplus.

The information from the S.A.C. is taken back to the field officers by district staff and management biologists, then provided as the raw material for the H.W.G. This group deals with all uses of herring and is chaired by the Herring Coordinator; its task at this time is to evaluate uses of the harvestable yield, logistics of the fishery in each area and local information to produce a roe herring quota for each stock grouping. At this point the advice of research biologists is examined from the practical and operational aspect of ensuring a roe fishery for the 1357 gillnet and 252 seine vessel licenses. In preparation for the other upcoming fisheries, the Fall Food and Bait Fishery Guidelines are drawn up, as well as management plans for Spawn on Kelp Fishery and live and sport bait use. For the roe fishery, quotas and gear splits are set out in different configurations for consideration by the H.I.A.B.

A sub-group, the Charter Committee meets just prior to this time to prepare a Charter Program for the upcoming roe fishery. Number of vessels, timing of charters and sampling needs are considered in preparing the plan to be presented to the H.W.G. and H.I.A.B., and invitations to tender sent out to drum seine vessels.

The H.I.A.B. meets at least twice annually, once in preparation for the fishery and once to review the season. At this time proposed plans for the roe fishery are reviewed and added to by industry representatives. Since its beginnings in the late 1970s, the Board has been reduced in number to only those representing users and has evolved from an information meeting to a forum for co-management.

The stock assessment and quota determination is presented in detail to H.I.A.B. members, as well as proposed roe fishery plans and other use fisheries. The industry members go into caucus and/or go to their membership before supplying the H.W.G. with their proposals for the roe fishery. These relate specifically to fishing areas and fleet distribution as well as food

and bait fishery and other uses. The final plan is drawn up from this consultation and the administration is begun to implement the decisions.

Another form of co-management is effected on the grounds with the addition of skippers of the charter seine vessels to the management team. The selection process for charter vessels, which takes place in late fall, emphasizes the skipper's experience and ability to participate in in-season management.

IN-SEASON MANAGEMENT

The herring season begins in earnest with local pre-season meetings both internal and with local industry.

Organization varies somewhat from area to area based on geography and fishing locations. In each case a field manager is responsible for everything about his fishery - soundings, roe tests, enforcement, and, most importantly, fishing to the quota. He is well supported by a team: biologists and other fishery officers on the grounds, and division staff and the herring coordinator in the major centres.

The season is reviewed by industry meetings both at the local level and at H.I.A.B. As this is happening, spawn assessment is taking place, starting the process again.

RECORDS

A significant contribution to this "consensus" system of management is the recording of planning and decision-making. This is done in two ways: through (1) recording and distribution of minutes of the S.A.C., H.W.G., and H.I.A.B. meetings and (2) the "Record of Management Strategies" used to record all pertinent in-season information including soundings, test sets, meetings and decision making for the sub-district officers.

CONCLUSION

Through this discussion I hope I have made it obvious that no one person is the herring manager. The entire fishery, from spawn assessment to planning, is a consensus of effort and perspectives.

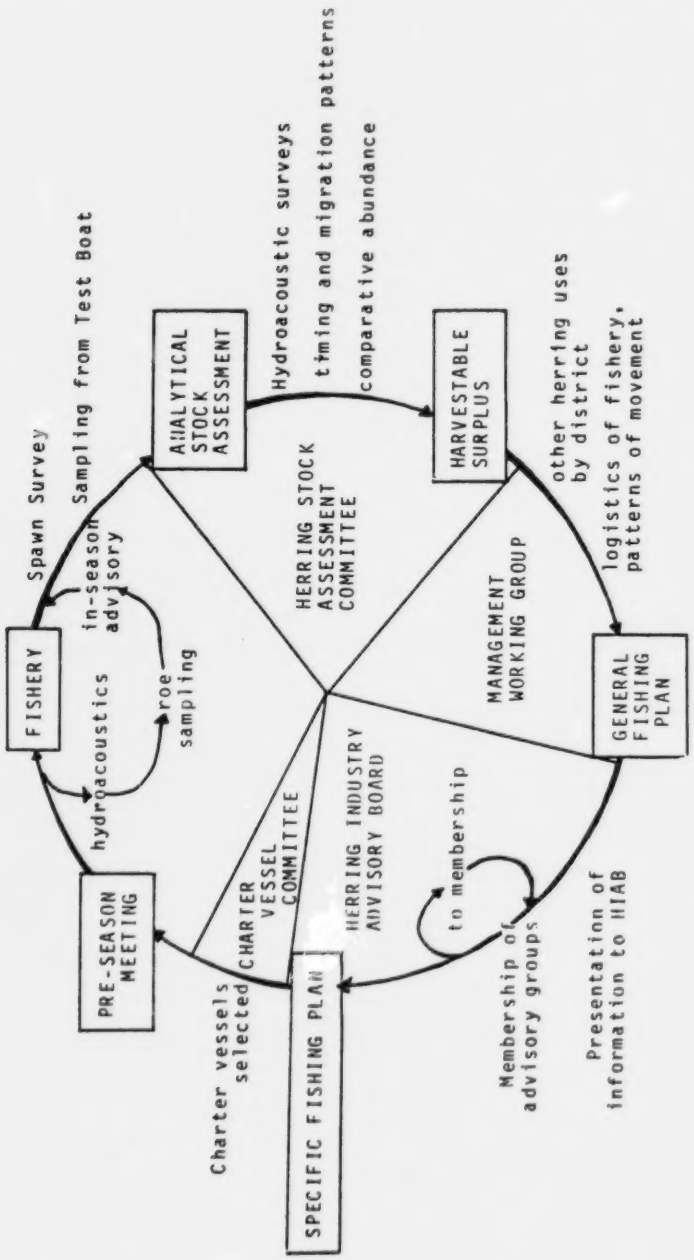

Fig. 1. Structure of herring management in British Columbia.

ROLES and PERSONNEL INVOLVED in HERRING MANAGEMENT

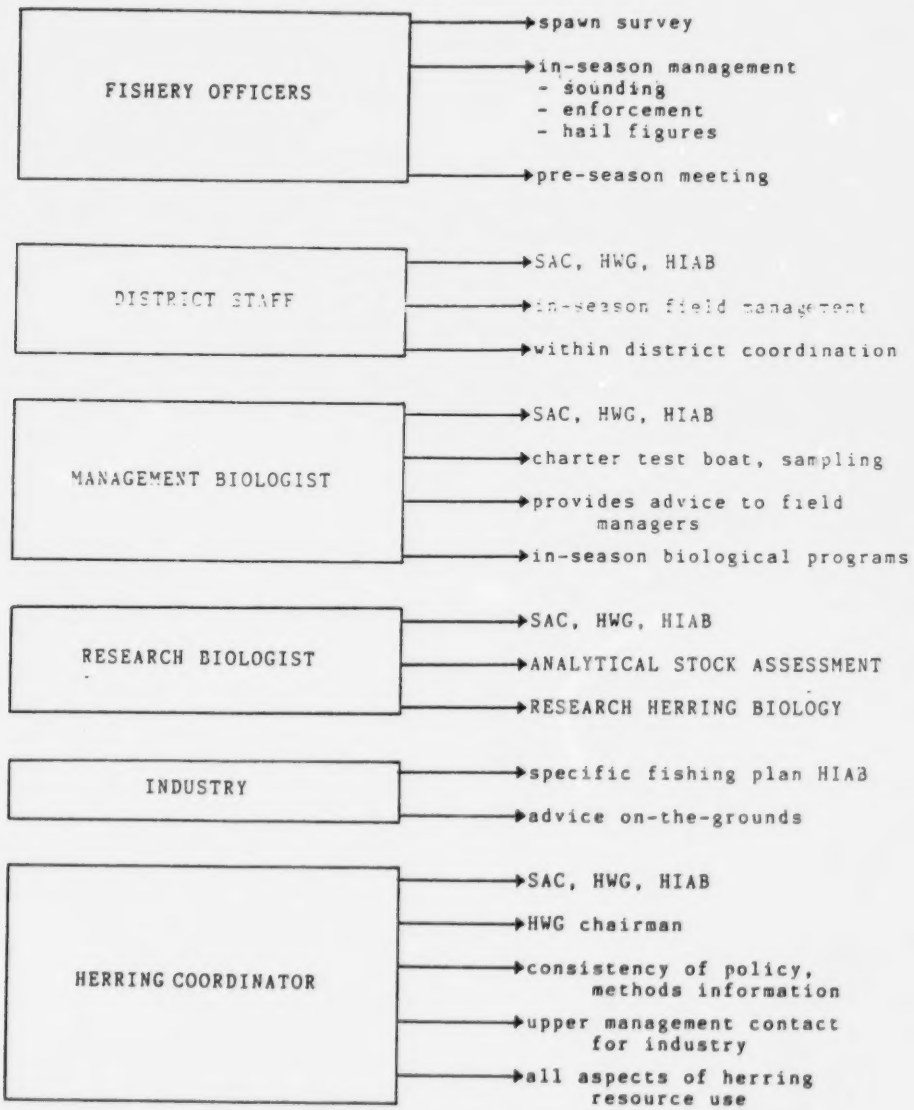

Fig. 2. Roles and personnel involved in herring management.

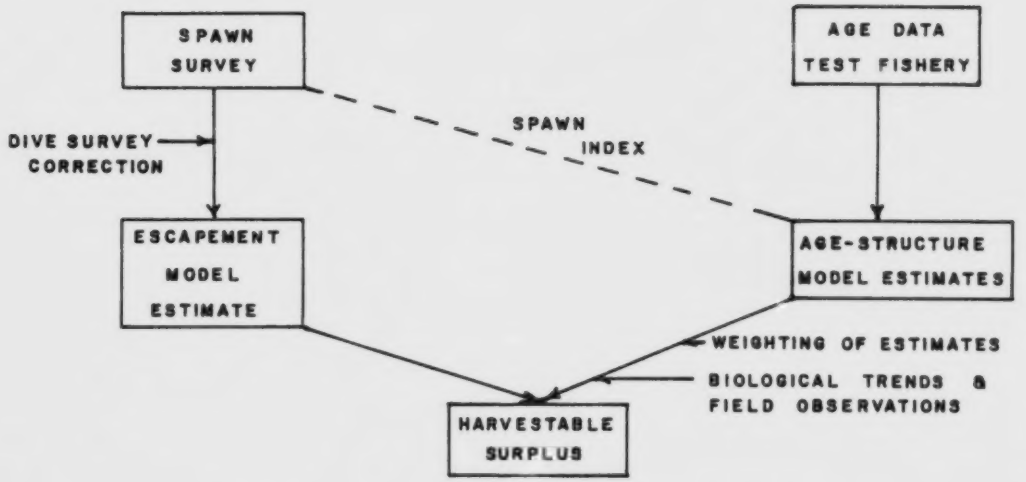

Fig. 3. Method of stock assessment.

Herring fisheries management and research in the Bering Sea

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DESCRIPTION OF THE ALASKAN BERING SEA COASTAL HERRING FISHERIES

The largest herring fishery in Alaska is conducted near the village of Togiak on the western end of Bristol Bay, about 80 air miles from Dillingham. Both gill nets and purse seines are legal gear, but only gill nets are allowed in most areas north of Cape Newenham. The Security Cove district immediately north of Bristol Bay is still open to all properly licensed fishermen, but Goodnews Bay, Nelson Island/Nunavak, Cape Romanzof and Norton Sound are now super exclusive registration areas. This means that if you wish to fish herring in any one of the above mentioned areas north of Bristol Bay, you cannot participate in any other herring fishery that year (in the State of Alaska).

South of Bristol Bay a small sac roe fishery operates in the Port Moller-Herendeen Bay area, and below this the Dutch Harbour food and bait fishery occurs in July and August.

Similarities in age and body size, a general knowledge of coastal migration patterns and limited local spawning populations, led to the belief that the Dutch Harbour fishery was affecting stocks from more northern districts. A scale pattern analysis was performed on samples from several coastal stocks, and it was determined that the Dutch Harbour fishery is, in fact, operating on mixed stocks, predominantly (80%) from Togiak. A new management plan to address this "double-dipping" will be discussed at the November, 1985 meeting of the Alaska Board of Fisheries.

All of these fisheries have originated or greatly expanded since the 200 mile limit, the Fishery Conservation and Management Act of 1976, and most are managed by emergency order with a 10 to 20% exploitation rate. The exceptions being Dutch Harbour, which has a 3200 t quota, and the Nelson Island/Nunavak fishery, which is managed for a 10% exploitation, to further protect the local subsistence economy.

Aerial surveys are the primary method of assessing the biomass in most districts.

DESCRIPTION OF THE BRISTOL BAY HERRING FISHERY

At Togiak the Department of Fish and Game staff have several management plans, and directives, that guide the fisheries. These mainly concern allocation between the two gear types, minimum thresholds of abundance for young and old year classes, optimum tide stages for the openings, which gear type fishes first, and the herring spawn on kelp and capelin fisheries.

Management of the Togiak fishery begins with registration of the companies on grounds, to determine fishing effort and processing capacity, and to open the lines of communication for catch reporting.

Gill net test fishing begins immediately, and as soon as herring are visible from the air, the roe maturity is intensively monitored with the use of purse seine test boats until the actual openings. Public roe testing is conducted on the beach so the fleet can compare roe recovery by area.

The Togiak fishing fleet is very large and efficient with 155 purse seiners and 302 gill netters participating in the 1985 fishery. This allowed only 11 hours of gill net fishing time and 3 hours of purse seining before the maximum exploitation (20%) was reached. The resultant harvest was 23,042 t.

The large harvest was also due, in part, to the large tender fleet employed by the 23 participating companies. Fortunately, near perfect weather allowed some herring to be held in RSW (refrigerated seawater) for over a week before processing.

HERRING RESEARCH EFFORTS IN BRISTOL BAY

Research efforts have been limited due to funding levels and the Department began managing this major fishery in 1977 with no equipment or staff specifically dedicated to the program.

The Bristol Bay staff are attempting to quantify and qualify aerial surveys, but much more work is needed, such as experimentation with side scan sonar in the shallow water to measure school density and calibrate it with visible surface areas of the herring schools at various water depths.

A graduate student from the University of Alaska, Fairbanks, has done very preliminary stock separation research on several western Alaska herring populations using otolith measurements. Early results from this effort were very encouraging and a large number of samples were collected in 1985 and are presently being examined.

Kelp regeneration studies were recently completed via contract work by University of Alaska, Juneau, graduate students, and greatly assisted in developing a management plan for this fishery.

Spawn deposition studies appear to be an unlikely tool in the Bristol Bay area for forecasting or estimating biomass due to the logistics involved and inter-tidal and sub-tidal spawns with multiple layers of egg deposition over large geographical areas.

MAJOR MANAGEMENT CONCERNS IN BRISTOL BAY

Bay weather and the inability to estimate biomass or conduct an effective fishery could result in a major loss in the quality and quantity of herring harvested.

Environmental degradation from oil spills and trash pollution, and also fleet avoidance due to the intense activity on the spawning grounds, may jeopardize the future of this fishery.

Multiple year class failures and the lack of significant recruitment could greatly reduce the available biomass at Togiak in the near future.

Herring interception offshore is reportedly common with large tonnages harvested incidentally by the drag fleets, both domestic and foreign. This removal is not well documented and is in addition to the full exploitation that has already occurred on many coastal stocks.

Evaluation of area licensing in the British Columbia herring fishery

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INTRODUCTION

Purpose

This report evaluates the performance of the area licensing program used in the British Columbia roe herring fishery. Area licensing was introduced in 1981 primarily in response to the management problems associated with the roe herring fleet's excessive fishing capacity. The evaluation attempts to determine the success of area licensing from two perspectives; the fishing industry and fisheries managers.

Background

The B.C. roe herring fishery began in the early 1970s. Due to the high incomes earned by roe herring fishermen, the fleet expanded rapidly (i.e., between 1972 and 1974 the seine fleet more than doubled while the gillnet fleet increased from 58 punts to over 1500 punts). However, until 1979 herring were relatively abundant and there was very few instances of large vessel concentrations at a single opening.

In 1979, there was a significant decrease in the abundance of herring which resulted in fewer fishing opportunities. This situation, combined with the large increase in fleet mobility during the late 1970s resulted in greater vessel concentrations at major openings. Area licensing was introduced in 1981 primarily to prevent extremely large vessel concentrations and thereby contribute towards an immediate improvement in the in-season manageability of the fishery.

STRUCTURE OF THE AREA LICENSING PROGRAM

The area licensing program adopted in 1981 had the following features:

a) the coast was divided into three areas and each roe herring license was eligible to fish one of the three areas;

b) the area choice applied for a period of one year; and,

c) licenses could not be transferred from one vessel to another during the season except where a vessel was lost or destroyed.

The original area licensing program has undergone the following changes since 1981:

a) the practice of multiple licensing began in 1982. Multiple licensing is defined as fishing more than one roe herring license area with a single vessel;

b) the three license areas were changed in 1985 in response to changing herring stock conditions; and,

c) fixed catch quotas, established pre-season for each license area, were adopted in 1983.

FISHING INDUSTRY REPRESENTATIVES' VIEW OF AREA LICENSING

The majority of fishing industry groups represented on the Herring Industry Advisory Board are satisfied with the performance of area licensing. Area licensing is credited with introducing some stability and order into the fishery which had developed a reputation for being extremely hectic. Specifically, the frantic running between locations in anticipation of openings has been greatly reduced and the number of vessels fishing in each area is lower due to area licensing. A large majority of fishermen indicated that area licensing has improved the management of the roe herring fishery and has contributed to a reduction in the cost of fishing.

While area licensing is viewed as a success by the majority of industry representatives, several problems associated with the program were identified. First, some seine fishermen did not like the risk associated with being limited to very few openings each season. Second, the unemployment created by multiple licensing and crews having to share in the cost of additional licenses were criticized by some industry spokesmen. Finally, there were complaints about the cost of leasing additional licenses and the fact so much money is being taken out the of the fishery by individuals leasing out their licenses.

FISHERIES MANAGER'S VIEW OF AREA LICENSING

DFO personnel believe that area licensing has improved the management of the roe herring fishery. The following management benefits are linked to the success of area licensing in preventing extremely large concentrations of boats at major openings:

a) the potential for overfishing is reduced as the number of boats fishing a given area is reduced (i.e., a large fleet is often capable of catching more fish than a smaller fleet and it is more difficult to keep track of the catches made by a large fleet and recognize when the target catch has been reached);

b) area licensing has prevented the occurrence of gillnets in an area exceeding the physical capacity of the fishing grounds.

While area licensing improved the fishery officers' capability to manage the roe herring fleet, it also increased the pressure to provide the pre-season anticipated catch in areas where stock abundance was unexpectedly low. However, the introduction of fixed catch quotas for each license area, in 1983, greatly reduced the pressure put on fishery officers. That is, fishermen know prior to the season the catch quota in each area.

In addition to improving in-season management, area licensing has made a significant contribution towards reducing fishing and packing costs. For example, the mobility restricting aspect of area licensing has reduced the fleet's operating costs, particularly fuel. Also, licensed seine vessels are able to act as fish packers to a greater extent since their actual fishing season has been shortened. Finally, the reduction in the size of the roe herring fleet due to multiple licensing will result in significant cost savings in the form of foregone expenditures required to outfit and maintain vessels for fishing herring (i.e., with a smaller fleet the cost of replacing vessels and equipment is reduced).

While DFO personnel acknowledge that area licensing has had a detrimental impact on some individuals, it is felt that greater hardship would have been experienced if area licensing had not been implemented.

OUTLOOK FOR THE FUTURE

During the 1970s herring stocks were relatively abundant in B.C. coastal waters (e.g., annual harvests of 36,000 to 77,000 t). The decline in herring stocks and annual harvests (23,000 to 34,000 t) experienced since 1979 combined with the increased mobility of the fleet resulted in fewer fishing opportunities and a trend towards large vessel concentrations at individual openings. Over the period 1981 to 1985 area licensing made a significant contribution to the roe herring fishery by maintaining an adequate fleet distribution relative to stock abundance.

However, with the low catch quota recommended for 1986 (i.e., 12,400 t), it is not possible for area licensing to achieve an adequate fleet distribution. Therefore, additional regulatory measures are needed to reduce the number of vessels participating in the 1986 roe herring fishery. It is likely that changes adopted for the upcoming season will be made within the structure of area licensing.

Alternative management strategies for British Columbia herring

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The objective of a harvesting strategy study is to explore the response of a population to different methods of stock removal. The technique of computer simulation allows the examination of many different hypotheses regarding population biology, harvesting strategies, and management uncertainty. This study examines the response of the Strait of Georgia herring population to three harvesting strategies; harvest rate, constant biomass, and constant catch. The age structured population model is evaluated for each harvest strategy by three criteria; average catch, catch variance, and risk. The model is extended to include uncertainty in stock assessment and the strategies are reevaluated.

The biological model is age structured in the form:

$$N_t = \sum_{i=1}^{10} N_{i,t-1} \cdot S_i + f(N) \qquad (1)$$

where:

N = population numbers
S = annual survival rate
i = age
t = year

and f(N) describes a recruitment function in the form:

$$N_1 = Eggs \cdot e^{a(1-(Eggs/b))} \cdot e^{v} \qquad (2)$$

where:

$$Eggs = \sum_{i=1}^{10} N_i \cdot fec_i \cdot mat_i \cdot 0.5 \qquad (3)$$

a,b = parameters
v = residual variance from regression of ln(N/Eggs) vs. Eggs
fec = fecundity
mat = proportion mature

Each harvesting strategy differs in the way catch and spawning biomass are determined. For the harvest rate strategy, both catch and spawning biomass are proportional to the prefishery stock size. The constant biomass strategy requires a fixed biomass of fish to spawn, with the surplus stock available for catch. The constant catch strategy takes the same catch biomass in every year, with the surplus stock making up the spawning biomass. In the simulation model, if the spawning biomass is less than the escapement goal in the constant biomass strategy, or less than the catch quota in the

constant catch strategy, then the catch in such years is zero. For the harvest rate strategy, catch is always some positive proportion of the spawning biomass.

The harvesting strategies are evaluated by three criteria. Average catch represents the grand average of 10 simulations of 15 years. Catch variance is calculated as the coefficient of variation for the 150 simulated years. Risk is separated into two types. Type 1 risk is the threat that the spawning stock will fall below a critical level of 20,000 t. Type 2 is the risk that catch equals zero because the spawning biomass is below the requirements of the constant catch or constant biomass strategies as described above. The results of the basic model are presented in Figure 1.

Management uncertainty is introduced to the model as uncertainty in stock assessment methods. The basis for the assessment of British Columbia herring stocks is the spawn survey, where the total egg deposition is estimated as the product of the spawn area and egg density for each spawn, summed for all observed spawns. Information is available from dual diver - fishery officer spawn surveys that allows an estimate of error for each component measurement; length, width and density. The model calculates two estimates of egg deposition. The first is the known egg number from equation (3). The second estimate is simulated from error distributions derived from the dual spawn surveys. The second estimate of egg deposition is converted to estimated spawning biomass in year t+1, following actual assessment procedures (Schweigert 1985, pers. comm.). The extended model is reevaluated in the same format as the basic model (Fig. 2).

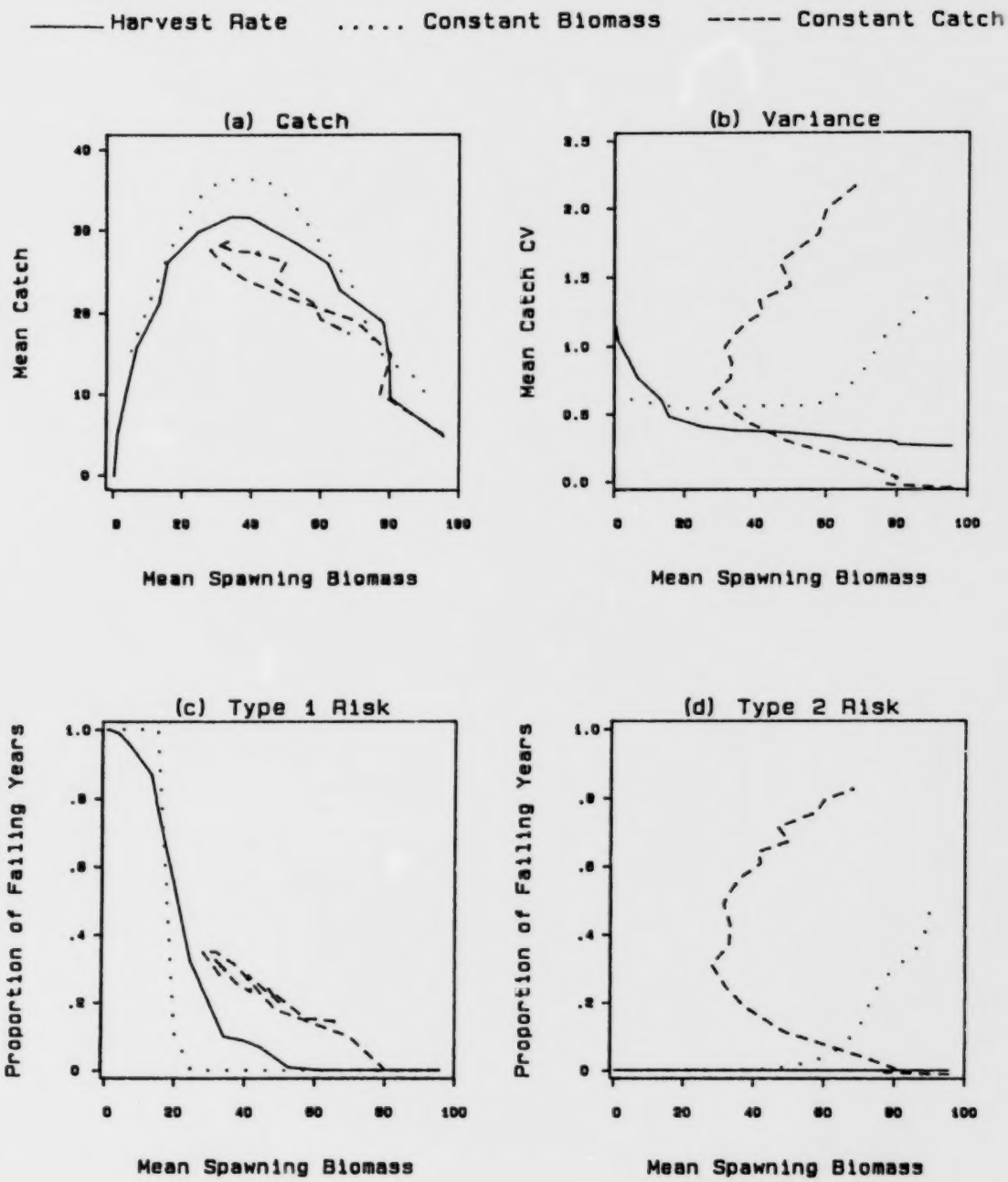

Fig. 1. Results of the basic model. Catch and spawning biomass in thousand metric tons. (a) Catch comparisons. (b) Catch variance comparisons standardized by mean catch (coefficient of variation). (c) Risk of spawning biomass less than 20000 mt. (d) Risk of no fishing because of insufficient spawning biomass for the constant biomass and constant catch strategies.

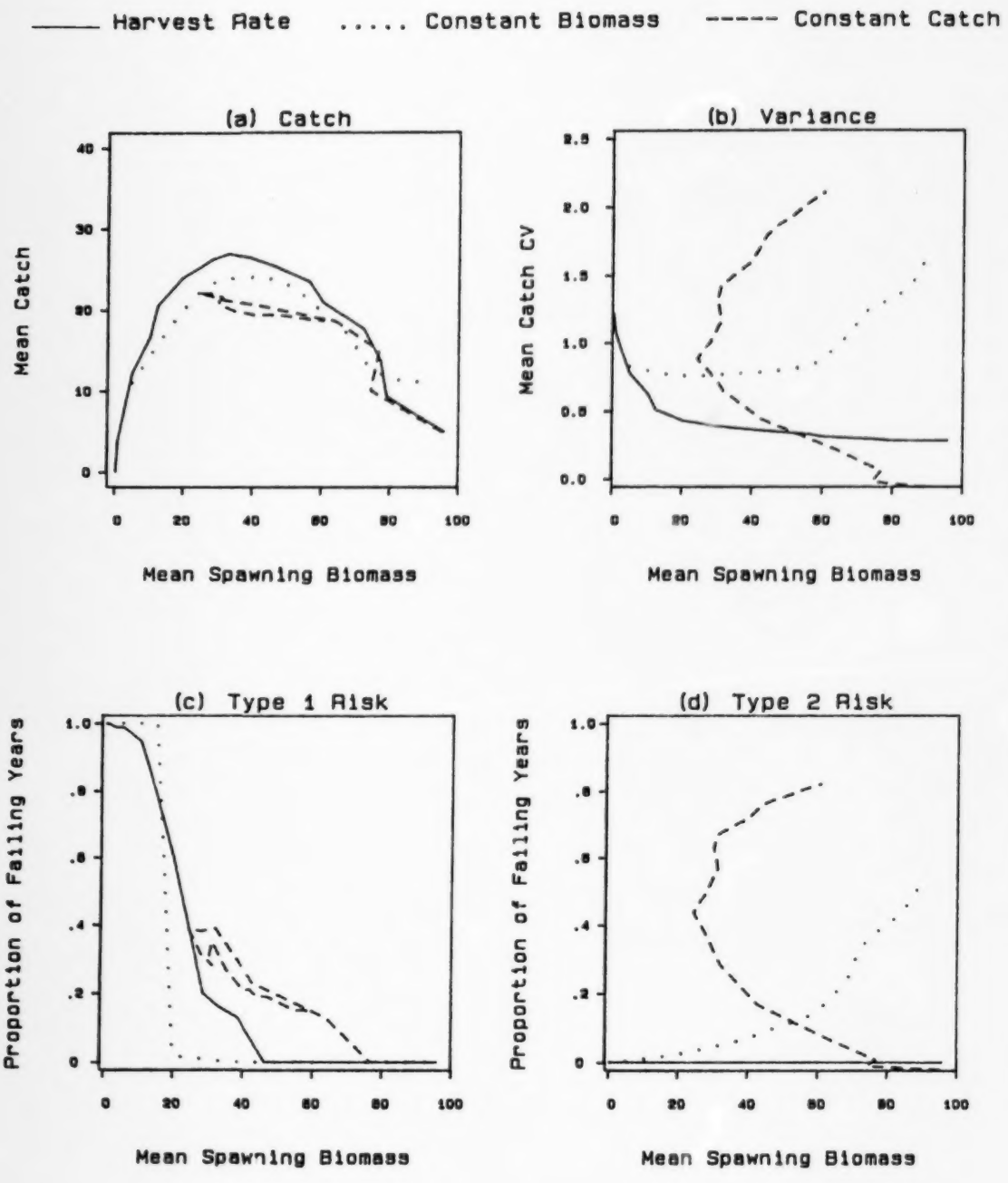

Fig. 2. Results of the extended model including management uncertainty. Catch and spawning biomass are in thousand metric tons. (a) Catch comparisons. (b) Catch variance comparisons standardized by mean catch (coefficient of variation). (c) Risk of spawning biomass less than 20000 mt. (d) Risk of no fishing because of insufficient spawning biomass for the constant biomass and constant catch strategies.

Development of management strategies for herring spawn on kelp fisheries, Prince William Sound, Alaska, 1969-85

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The herring spawn on kelp fishery in the Prince William Sound Area (Fig. 1) began in 1969 in response to a developing Japanese market for herring roe products. Markets were eventually established for several species of broad-leafed brown kelps and fishermen first gathered the product with the aid of a grappling hook attached to a line and operated from a small boat. The fishery has undergone a major transformation during the past 15 years influenced by marketing adjustments, changes in harvest technology and the development of regulations in response to biological concerns. This evolution has included three phases of development starting with the early period in which the fishery was virtually unregulated and harvesting techniques were nonselective due to the use of grappling hooks. The second phase started during the late 1970s when a production quota was established and, in response to concerns over the potential adverse impact of the fishery on the kelp resources, the harvesting was restricted to the hand cutting of selected kelps by divers. The third and most recent phase has included the development of an even more selective and cultured process for producing herring spawn on kelp through the use of herring impoundments. This type of production has developed rapidly since 1979 and has been permitted to expand at the expense of the more traditional fishery harvesting natural spawn on kelp by divers. Separate allocations and regulatory guidelines have evolved for each fishery but the combined harvest levels for all area spawn on kelp fisheries has remained unchanged. Since the available herring resource is fully utilized by all the various spring herring roe fisheries, these adjustments have been possible only through a gradual shift in the allocation from the dive kelp fishery to the pound kelp fishery rather than by an increase in the overall exploitation rate.

Harvest trends have fluctuated widely since the inception of the spawn on kelp fishery ranging from a total closure of the dive fishery during 1984 to a peak harvest of 416 t during 1975 by 437 fishermen using grappling hooks. Since the pound kelp fishery started in 1979, participation and production has increased to a peak of 36 t of processed product by 59 pound operators during the 1985 season.

A mixture of both economic and biological considerations have combined to help shape the current direction in the development of management strategies for this constantly changing fishery.

DISCUSSION

Natural Spawn on Kelp Fishery

With the advent of the herring spawn on kelp fishery in Prince William Sound, the absence of any special regulations or harvest management strategies led to a rapid increase in production from less than 3 t by only a few fishermen during 1969 to a peak harvest of 416 t by more than 400 fishermen six years later (Fig. 2). By this time it became apparent that the nonselective harvest of spawn laden kelp was potentially harmful to the kelp substrate when a majority of the harvest occurred in a concentrated area. This nonselective method of harvest in a small area during 1975 resulted in the denuding of entire kelp beds that threatened the revegation by the plants and the maintenance of a healthy spawning substrate. Studies were initiated the following year to investigate the situation and recommendations that were made as a result of this work ultimately led to the adoption of regulations restricting the method of harvest to hand cutting of the plant by divers (Rosenthal 1977). The Alaska Board of Fisheries adopted regulations for the 1977 season that limited the harvest of the kelp to the use of a hand held unpowered blade cutting device and the removal of the plant at least four inches above the stipe or meristematic zone. This change heralded in a new era in the evolution of the kelp fishery by not only minimizing damage to the spawning substrate but was also well suited to the selective harvest of those species of broad-leafed kelps that comprised the majority of the local market. Both ribbon kelp (Laminaria sp.) and sieve kelp (Agarum sp.) have a prominent holdfast and stipe with a broad blade that is readily separated with the use of a sharp cutting device and these two kelps are the two most marketable species. The State established an annual kelp monitoring program and after six years of study it became evident that the local flora undergoes natural fluctuations independent of the impact of the fishery (Fig. 3). It appeared that as long as the kelp standing crop was maintained at a biomass of 1 $kg \cdot m^{-2}$ or higher a kelp harvest could probably be justified. What actually happens is that due to a normal shift in the annual spawning distribution and the tendency of the more selective fishery to relocate to the healthiest kelp beds there is the likelihood for the harvest to rotate to new areas, allowing for recovery of kelp beds following a harvest.

A harvest guideline was also established for the first time in 1977 and was initially set at 150 t. This was increased to 181 t for the 1979 season and remained at that level until a gradual process of reallocation to the developing pound kelp fishery began in 1982. A local harvest permit was required during the early years of the fishery to monitor potential effort prior to the season. This requirement was eliminated after 1984 since effort estimates are normally possible on the fishing grounds and through licensing data. This fishery is currently managed on an emergency order field announcement basis with openings adjusted depending on the timing, distribution and density of spawning. Biological concerns over the impact on the kelp resource have been addressed through changes in the harvest regulations. The potential for wastage of both the herring spawn and kelp still exists through the harvest of unmarketable product by inexperienced fishermen. These concerns have resulted in severe limitations being placed on

the harvest in some years and resulted in a total closure of the season during 1984. Due to the scattered distribution and long duration of the spawning that season, the egg coverage was never of a suitable quantity and marketable quality to justify a commercial harvest. Isolated pockets of marketable coverage were available but were never considered for harvest because of the potential for wastage and the likelihood of completely denuding the local kelp substrates. Typical of many other fisheries, the whims of both mother nature and the marketplace determine whether any season is going to be a success or failure for the hundreds of fishermen who participate in the wild spawn on kelp fishery. Success is dependent on a unique combination of eggs and kelp. In order to be marketable, the harvest must contain clean kelp of a particular species, have spawn of adequate density, and occur within a relatively short span of time before the eggs begin to eye out. Depending on the outcome of pending allocation questions and due to the normal variations in the distribution and intensity of herring spawning, there will continue to be changes in the timing, location and relative success of this fishery.

Due to a loophole in the regulations that existed prior to 1985, the development of an "open pound" type of spawn on kelp production was attempted for several years in conjunction with the traditional dive fishery. Several fishermen were partially successful in producing some product by placing kelp on lines in traditional spawning areas in an effort to attract natural spawn and in anticipation that there would be an eventual opening of the wild spawn on kelp fishery in the same area. This technique was attempted for several years and, although unconventional, was not illegal by the fact that the regulations did not specifically prohibit it. It was eventually outlawed because of the potential for wastage of the resource, the inability to control illegal production, and the difficulty of managing for a controlled harvest.

Pound Spawn on Kelp Fishery

In response to both the marketplace and the desire to eliminate some of the uncertainties that have plagued the wild kelp fishery, a relatively small group of fishermen have been developing Alaska's newest herring fishery, a pound spawn on kelp fishery. Although many of the techniques have been adapted from a similar fishery in British Columbia, several unique variations have developed as a result of both local market influences and differences in agency regulation of the Alaskan fishery. Participation in the Alaskan fishery is not restricted by limited entry so the only control on the number of operators tends to be the economic considerations of individual fishermen. An annual quota has been established and the allowable harvest is equally divided amongst those fishermen actually participating. The recent development of the pound culture of herring spawn on kelp has been an outgrowth of the more traditional dive kelp fishery and has involved many of the same participants. The pound fishery is more specialized since it requires a broad range of fishing skills and equipment including the construction of a portable fish impoundment structure, diving equipment for the gathering of kelp, a spotter plane to locate the fish, a purse seine and boat to capture the herring and knowledge of the handling and processing of the final product. Most pound operators tend to work in cooperative arrangements with other fishermen to pool their different resources and skills.

The pound fishery was first permitted on an experimental basis in 1979 with a guideline harvest level of 7 t. Because there was already an existing kelp fishery and there were many uncertainties about how best to manage the harvest, the initial guidelines that were adopted attempted to resolve not only potential user conflicts but also addressed management concerns of how to monitor and regulate the harvest and minimize damage to both kelp and herring resources. An annual permit application deadline has been established so prospective fishermen have some advance idea of the likely competition, but there is a further provision that the available quota is later divided equally amongst those applicants who actually construct a pound by a specified date. During the first few years the fishery was restricted to a specific location, that not only provided essential protection from the weather and a dependable supply of kelp and herring but was also far enough removed from traditional wild kelp and purse seine sac roe fishing areas to avoid conflicts, yet was localized enough to permit close monitoring by the Department. Important biological safeguards were built into the permit provisions including the requirement that herring be released after a specified amount of time and that the pounds were to remain in the water until all fertile eggs had hatched. Since the adverse impact on the herring due to high loading densities was a problem from the outset, a maximum allowable level of herring utilization was also equally divided amongst the permit operators and a minimum pound surface area requirement was imposed. Assuming an 85-90% average egg weight on the harvested product and a 10% average roe recovery from the herring population, a pound operator would require 8.5 to 9.0 t of herring to produce a tonne of finished eggs and kelp. The actual amount would be higher, however, since this assumes 100% spawning of all fish and does not allow for dead loss and spawn that is lost through discarding or what is deposited on the pound webbing and ribbing. The removal of the productive capacity equivalent to 10 to 13 t of herring for each tonne of finished spawn on kelp was selected as a reasonable working level for this fishery (Randall 1982).

During the first year of the fishery pound operators that utilized local ribbon kelp were required to remove the holdfast and regenerative part of the plant before placement into the pound. This was eventually modified to permit the removal of the entire kelp plant to facilitate their attachment on lines for placement in the pounds. This was felt justified after the first season since the kelp gathering process for pounds is very selective with very little likelihood that any kelp beds would be severely denuded. This harvest can be carefully monitored and only a few tonnes are removed which represents a minuscule portion of the total standing crop in the area. Another important biological concern had to do with the potential impact of seining for fish in areas where damage could result to valuable kelp beds utilized by the dive fishery or on kelp that had already received herring spawn. Field management of the fishery continues to discourage the opening of areas where spawning has already occurred or where potential natural kelp harvests could develop.

Numerous changes in the permit specifications have been made over the years and the management has been gradually streamlined, but the most significant trend in recent years has been the gradual reallocation of the production quota from the dive kelp fishery to the pound fishery. This process began in 1982 and, following two additional reallocations, the pound

fishery has had its quota increased to 36 t while the dive fishery allocation has been reduced to 153 t. The original reallocation set a precedent since, rather than being an equal exchange, a formula was adopted which resulted in 1.2 t reduction in the wild quota for each one tonne increase in the pound allocation. The logic behind a proportionately greater decrease in the wild kelp harvest was based on a higher documented egg weight to kelp weight ratio for the pound produced product (assume 80% egg weight on pound kelp and 60% egg weight on wild kelp or a ratio of 1.3 to 1). This approach recognized that all herring stocks are fully allocated amongst both kelp and sac roe fisheries and that even though they do not harvest the herring directly, kelp fisheries nonetheless remove an equivalent amount of reproductive potential from the available population.

Through time, the responsibility for the permit revision process was shifted to the area office. This provided more flexibility in the field management of the fishery and eliminated the more cumbersome and time consuming process of making formal regulation changes each year. Without a doubt, the most challenging area for management has had to do with the development of a scheme for obtaining reliable production data and achieving a specified harvest goal. Problems still persist in the area of monitoring and verification of final production from individual pound operations. Permit holders can be involved in the day to day operation in a somewhat remote and absentee fashion, which differs from other fisheries where the gear operator has hands on involvement in all phases of the process. The pound fishery differs from others in that operators work in cooperatives and are vertically integrated with no traditional buyer-seller types of checks and balances in the harvesting and processing steps. Operators oftentimes process and even market their own product and issue their own harvest tickets. There exists the potential for underreporting of the actual harvest and, in addition, reported weights are the trimmed and final processed weight. There is intense competition for individual production shares since fishermen operate under a quota type harvest guideline. The harvesting normally involves the culling of eggs and kelp from lower grade coverage product to maximize quality and stay within the allocation but results in the loss of potentially viable kelp and eggs.

Recent efforts to more closely monitor the harvest and assure that the allocations are not exceeded have involved limitations on the amount of kelp that can be introduced into each pound. Allowing for an average weight gain for all pounds, it was assumed that the overall harvest guideline could be maintained by restricting the weight of kelp that could be placed in individual pounds. Regular sampling of both raw kelp plants and the finished kelp and eggs had helped quantify the normal weight gain relationships for this fishery. The two types of kelp currently used in this fishery include the ribbon kelp, which is available locally, and the giant kelp (Macrocystis sp.), which is imported from southeastern Alaska (Dall Island and Sitka Sound). Initial sampling was limited to local ribbon kelp since it was the most popular kelp during the first few years and these results suggested a weight gain factor of 7.4 times the raw kelp weight (Randall 1982). These early measurements were taken from the raw unprocessed product and were not comparable to the weights reported by the pound operators since a significant amount of the weight is lost due to trimming during the processing and

packing. Subsequent sampling during 1983-84 included both giant and ribbon kelp specimens and revealed an unprocessed weight gain factor of 5.3-6.2 for ribbon and a factor of 5.4-9.2 for giant kelp (Brady 1985). The most significant results, however, were that the processed weight gain factor for ribbon kelp was much lower (2.8) than for the giant kelp (5.4). This was consistent with the lower weight gain factor reported by the pound operators and was apparently due to the differences in weight loss during processing. Egg coverage on ribbon kelp is frequently quite variable and as a result a significant portion of the plant (including area of egg coverage) is trimmed off and discarded. Giant kelp blades, on the other hand, are flat and lacking the ruffled edges typical of the ribbon kelp, and tend to receive a more uniform coverage of eggs. As a result, less of the blade surface has to be trimmed off and discarded when the product is processed and presumably fewer eggs are wasted. Using this information the pound operators were limited during 1985 to a total raw kelp weight that was equal to 20% of their individual allocation based on the assumption that a 500% weight gain could be achieved. This change tended to reduce the amount of excessive kelp normally used by the fishery but, with limited manpower to adequately monitor all 59 pounds, verification of actual production success remains difficult. Faced with limitations on the amount of kelp that can be used, there is also the tendency to maximize the egg coverage by introduction of an excessive amount of herring in some instances. Figures on the tonnage of herring introduced into each pound are based on visual estimates and depend on the individual experience of technicians, spotter pilots and pound operators.

Faced with the likelihood of a continued rapid expansion in the level of participation in the pound fishery, the challenge of managing for a particular harvest will become more difficult. As the fishery continues to evolve and new production and management techniques are developed, the process should become more efficient.

SUMMARY

The major factors that have helped shape the development of strategies for Prince William Sound's herring spawn on kelp fisheries have included a blend of economic, biological and harvest management considerations. Maximum flexibility has been permitted in the development of the fishery in an effort to optimize the value of the harvest. Harvest methods have been developed that provide for a more selective harvest that ultimately produces a higher quality and more valuable product. The introduction of more selective harvest techniques also helped resolve biological concerns over the potentially adverse impact of the fishery on the health and long term survival of important kelp spawning substrates. The development of a locally operated and flexible management scheme has also led to the reduction of potential wastage of the resource since it is able to react on short notice to changing conditions.

The evolution of the pound kelp fishery has created new challenges for management but has helped eliminate some of the uncertainties of the wild

spawn on kelp fishery and has provided the opportunity to use more valuable kelp species that were not available locally. The considerations that have helped shape the direction of both fisheries have been similar since flexibility has been permitted to allow for reasonable growth and optimum economic value. At the same time, biological safeguards have been built into the scheme that should help reduce unnecessary adverse impacts on the kelp and herring resources. A complex set of permit specifications has also evolved in response to efforts by management to more effectively monitor and regulate the harvest within established production guidelines.

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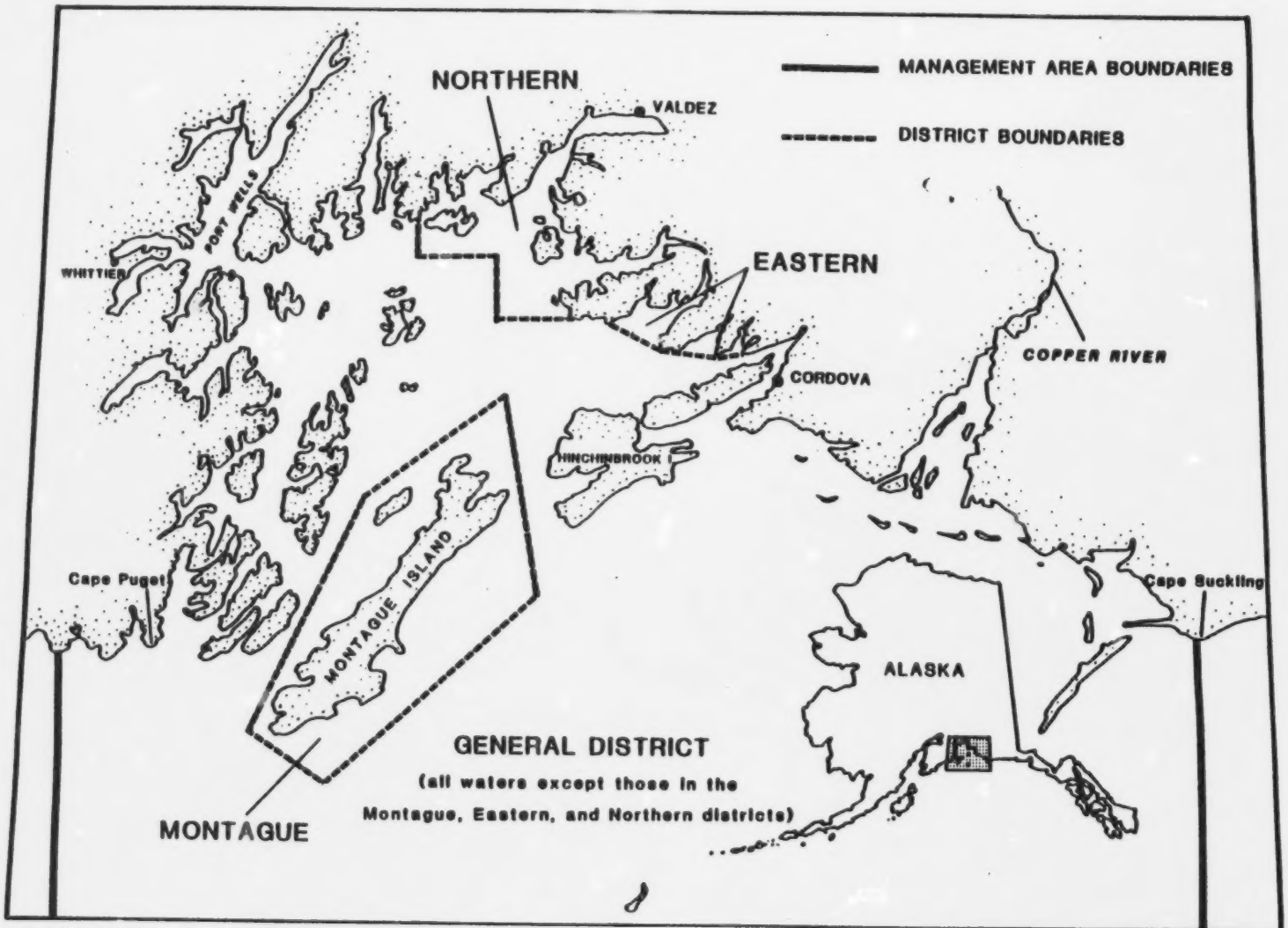

Fig. 1. Prince William Sound area herring management districts.

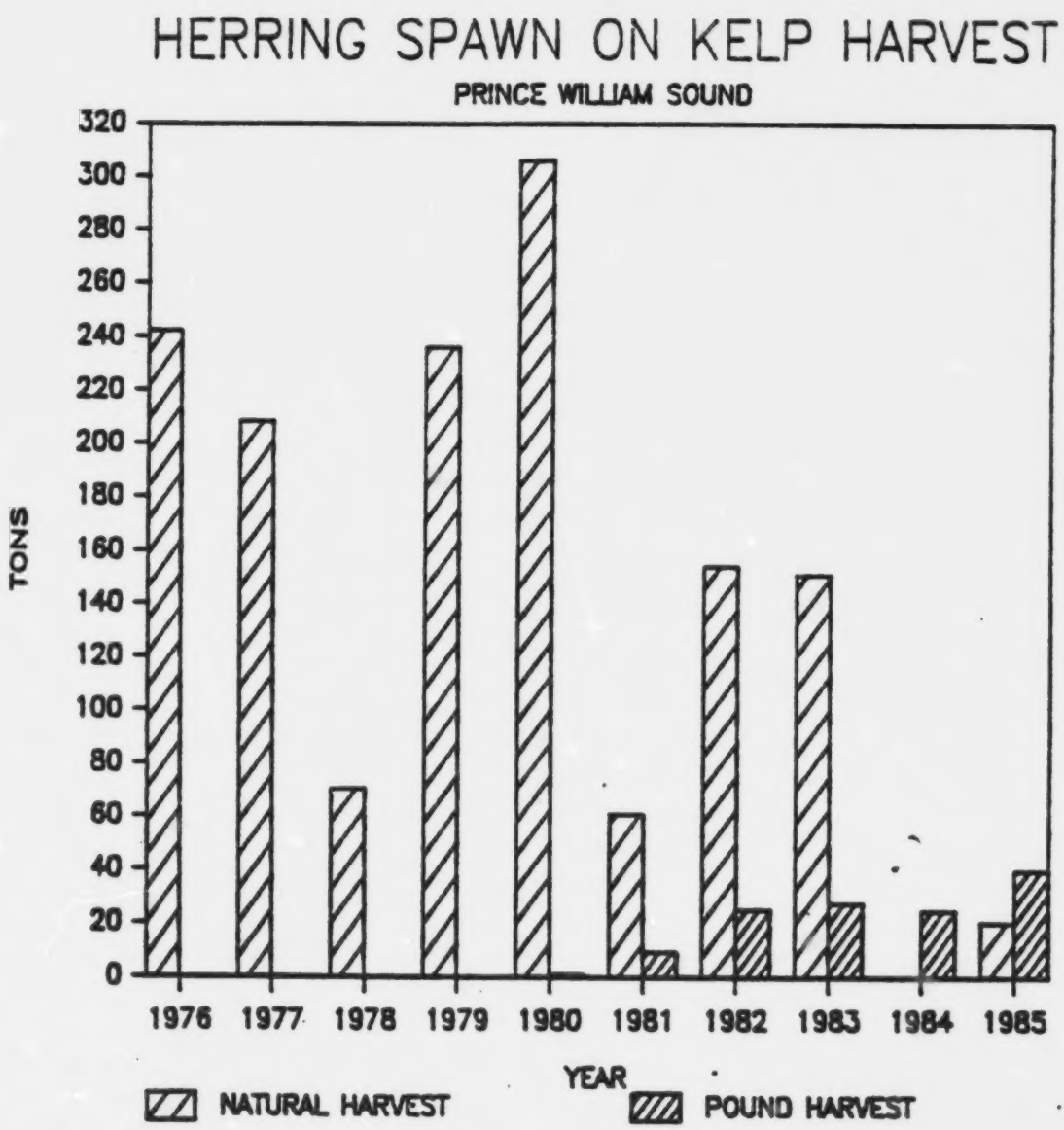

Fig. 2. Herring spawn on kelp harvest, Prince William Sound 1976-1985.

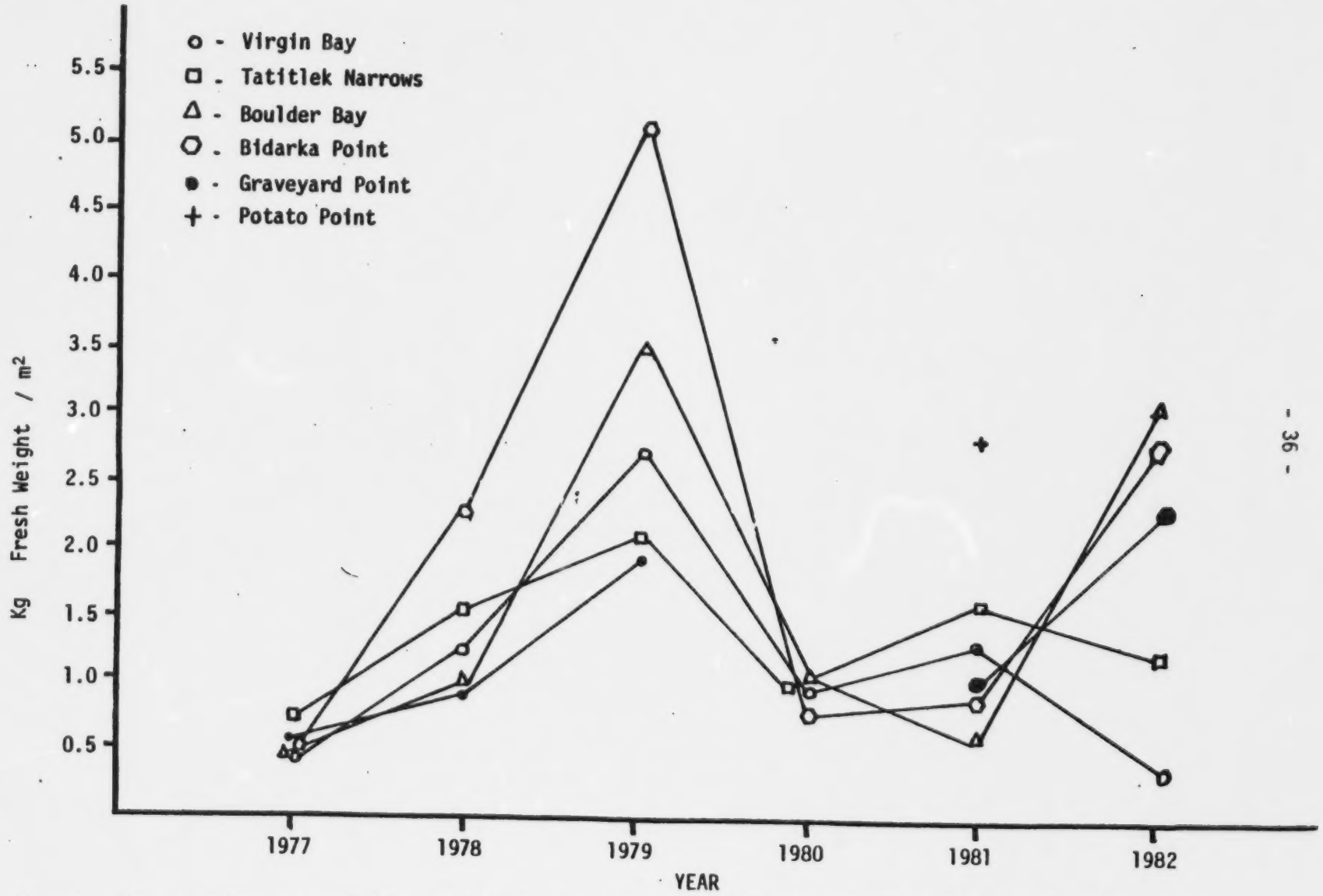

Fig. 3. Mean standing crop of kelp during April at selected study sites, Prince William Sound, 1977-1982.

Progress in sac-roe impoundment research and options for management

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Sac-roe impoundment is the capture of maturing adult herring away from the spawning grounds, prior to final maturation, and transfer to a holding facility where maturation is completed normally. The key point is that spawning is inhibited, allowing the harvest of marketable roe herring without the intense competition of a seine fishery opening and its possible negative biological effects. The mechanism of spawn-inhibition is not known, but may be represented by a complex of factors including sufficiently long pre-maturation holding period, unnatural surroundings, presence of biological fouling on potential spawn substrates such as pond webbing, and isolation from natural spawn-behaviour releasers. The effect is to reduce to a very slight probability the chance that an accidental spawning might occur.

Extensive technology has been developed at the Pacific Biological Station for holding pens of up to 30 t capacity, handling techniques for large tonnages of live herring, methods of transport (towed-seine, towed semi-submersible live-barge, and holding-pens modified for cost-efficient high-volume transport), holding-density/duration relation to survival, and maturation date- and yield-forecasting. Roe from experimental impoundments has been processed commercially, and market-tested with high acceptance. An economic analysis has indicated potentially high benefit-cost ratios for the technique, up to 11:1 for a 200 t operation using previously unfished smaller stocks. Analysis of 3 years' commercial roe-retrieval data indicates that impoundment technology permits an average increase in harvest tonnage of first-grade roe of 15 to 17% over what an ideally-timed seine opening could achieve on the same stock of fish. The increased yield peaks at about 2 weeks after the date on which the rate of increase in main roe weight levels off, indicating general maturation. The increase in yield results from slower-maturing roes catching up to the main trend while spawning delays, allowing them to be graded as Number 1 rather than Number 2 or poorer as they would have been in a seine opening, which must take place before the main stock begins first-wave spawning. While the gross tonnage of roe harvested is not demonstrably increased by the impoundment technique, the quality of the harvest is improved considerably, compensating substantially for the essential non-selectivity of the seine as a catching gear.

Thus, sac-roe impoundment technology offers a means of improving the harvest efficiency of the roe herring seine fleet, a consideration likely to be of interest to vessel-owners contemplating fleet economics particularly the low annual mean catch per vessel (approx. 30 t during years 1980-84). However, in addition to improving seine fleet efficiency, use of impoundment technology could also realize several major resource management objectives:

1) Fleet rationalization/relief of concentrated pressure on resource: in locations where smaller biologically discrete stocks are too vulnerable to fish under current legislation, a number of permits for impoundments,

based on an appropriately conservative stock exploitation rate, would justify transfer of a proportionate number of seine-licences from the open fishery. The permits could be clustered for economy of enforcement, and time-windows assigned during which catching operations could proceed without the tension, risk, and pressure of an opening. An option would exist in some cases, allowing the increased access to the open fishery to be shared among remaining seiners only, or between seines and gillnets, in addition to the original objective of reducing fishing pressure. The economic analysis indicates that a substantial licence fee or catch royalty could be accommodated, of at least the order of current non-native seine licences.

2) Local fishery diversification: an impoundment operation has the potential for generating a high rate of return in a short time, and could well pay for its entire capital expense plus show a profit in one season. Under an appropriate economic-zone management structure, revenues generated by a herring impoundment could act to subsidize more marginal fisheries, e.g., for a fishing co-operative, or to carry the heavy start-up costs for such other marine resource industries as salmon farming or gourmet seafood specialties.

Admittedly, both these options require some philosophical leaps. Using impoundments for fleet rationalization introduces by default the concept of vessel quotas. Short-circuiting revenues from an impoundment back into a local marine resource economic zone could be viewed pessimistically as contrary to the common-property resource management concept. However, current resource management philosophies already recognize underprivileged and disadvantaged groups, and some of the elements of a revised management approach can be viewed as already in place. It is axiomatic that political will must propel the concepts described above, but there appears to be ample incentive, both from the perspective of current herring fishery trends and from the perspective of impoundment research findings, to justify making changes in how we exploit Pacific herring.

Research in sac-roe impoundments is now essentially complete, and awaits commercial piloting in a small number of locations to indicate any outstanding issues. A comprehensive methods manual for prospective operators is now in press, and a position paper is in preparation, to address the specific possibilities and constraints on impoundment development on a region by region basis for the British Columbia coast, including identification of possible sites, stock assessment needs, enforcement issues, and some proposed solutions. Research continues on 2 related issues, the control of spawning in herring, and the use of hydroacoustic techniques for biomass estimation in holding pens. Published literature including 5 technical reports and the items referred to above are available from the Pacific Biological Station.

SESSION 2

STOCK STATUS AND LIFE HISTORY

A preliminary evaluation of an Arctic herring stock

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Economic opportunities for residents of Canada's Northwest Territories are limited. Development of renewable resources such as fishing can provide a much needed source of revenue. However, rather severe biological and economic constraints limit fisheries to a small scale if long term viability is to be maintained. Therefore, success depends upon producing low volumes of high value products.

The Minister of Renewable Resources for the Government of the Northwest Territories requested the Department of Fisheries and Oceans (DFO) to investigate the development of commercial fisheries in the Beaufort Sea/Mackenzie Delta areas. The presence of Pacific herring, Clupea harengus pallasi, in the nearshore Beaufort Sea and Liverpool Bay has been known for some time. An experimental carcass fishery was carried out near Baillie Island in 1963 but failed due to high production and transportation costs. However, the spectacular success of the herring roe fishery on Canada's west coast has renewed interest in this resource. In relation to its volume the roe is a high value product making it somewhat more suitable for commercial development than other species present.

Considering the above, DFO initiated a study in Tuktoyaktuk Harbour (Fig. 1) in the fall of 1980 to determine time of spawning. Periodic gillnetting through the ice and monitoring of the gonosomatic index (GSI) revealed that spawning began about mid-June in 1981. Unfortunately this was coincident with ice breakup making fishing extremely dangerous. The investigation was moved about 90 km east to the Fingers area of Liverpool Bay (Fig. 1) where more favourable conditions were known to occur. Widespread gillnetting throughout the Fingers area in early June 1982 revealed herring at all locations fished, with the best catches in Fingers 1 and 2. A small experimental roe fishery was then conducted in 1983 and produced 398 kg of roe from 4580 kg of herring. This product was shipped to the Prince Rupert Fisherman's Co-operative Federation for evaluation and was considered marketable. The next step was to evaluate the herring stock to determine if it was sufficiently large enough to sustain a harvest of some commercial value. At present market roe prices, a quota of at least 50 t of herring would be required to make such a venture worthwhile.

Spawning stock assessment was based on a spawn deposition study carried out in 1985 along about 500 km of shoreline by divers using SCUBA (Fig. 1). Baseline biological data were collected since 1982 to back-calculate the size of the spawning stock from total egg deposition. Fishing began through the ice prior to spawning and, although a variety of mesh sizes were used (38, 57, 64, 89, 114, and 139 mm), very few immature herring were taken. Most of the catch was taken in the 57 and 64 mm mesh. In Liverpool Bay spawning began about mid-June when surface water temperature was 2.5-3.5°C. Mean GSI of females was about 17 to 21. Size of first maturity

appeared to be about 210 mm, standard length. Spawners ranged in size from 210 to 320 mm. The modal size of spawners in Tuktoyaktuk Harbour was 270-290 mm whereas modal size of spawners in Liverpool Bay was somewhat smaller at 260-280 mm (Fig. 2). Age of first maturity appears to be about 8 years with modal age between 11 and 12 years (Fig. 3). Spawners ranged in age from 8 to 16 years. In 1982 and 1983 the sex ratio favoured males by about 2:1.

The Fingers in Liverpool Bay were divided into five sampling areas in 1985, primarily for logistic reasons (Fig. 1). In each area the sex ratio was nearly equal, the samples being taken just prior to spawning.

Fecundity analyses on samples taken from areas 1, 2, 4, and 5 revealed that fecundity is linearly related to weight. Therefore, relative fecundity is constant, not being influenced by age or weight. However, results of analysis of covariance indicate that fecundities at the grand mean log length or total weight differ significantly between areas, which precludes the use of a grand mean relative fecundity for estimating the biomass of Liverpool Bay herring. The mean relative fecundity for each area must be used. These are, in eggs/female gram: Area 1 = 116.5 (N=50); Area 2 = 150.3 (N=46); Area 4 = 151.1 (N=65) and Area 5 = 135.6 (N=13). Whatever the reason(s) for differences in mean relative fecundity between areas, all values fall well below the 200 eggs/female gram characteristic of British Columbia herring.

A simple comparison of growth shown as length at age in Figure 4 suggests that the growth rate of Liverpool Bay herring is similar to that of herring from the southern Strait of Georgia. However the Arctic herring attain a much larger size and greater age. Since the data represent spawners, it appears that British Columbia herring spawn at a smaller size and younger age than the Arctic herring and they appear to have a higher fecundity. Perhaps these characteristics can in some measure be attributed to the continued exploitation that the southerly stocks have been exposed to for many years, as well as to the effects of latitude.

Results of the spawn deposition study indicated that spawning began in the Fingers area on June 13, 1985 and perhaps earlier. Spawning activity appears to be somewhat protracted as spawners were taken as late as July 16. The herring spawned on substrate located along shallow mud/sand flats in 1-4.5 m of water. Water temperature during incubation was 10-12°C and salinity ranged from 6-12°/$_{oo}$. At greater depths water temperature was lower, salinity was higher and no eggs were observed. Major spawn substrates included tundra debris, aquatic plants similar to Zostera marina and to some extent leafy red algae (Callophylus sp.). Incubation appears to take about 24 d.

It is estimated that 3.74×10^8 herring eggs were deposited in the study area, although rigorous statistical treatment of the data has not yet been completed. Ninety percent of the eggs were discovered in Fingers 1 and 2 and the approaches to the Kugaluk River estuary. Total deposition suggests that about 5 t on herring spawned in the area assuming 7.5×10^7 eggs per

tonne of herring (males and females). Based on larval recovery, two separate spawnings in early June may have been missed in the Kugaluk River estuary as well as a spawn in the NE portion of the study area. Low concentrations of herring larvae at these sites and in the remainder of the study area suggest that no major spawns were missed, and that this area does not support a large spawning stock of herring.

These preliminary results, although not complete, suggest that there may be insufficient numbers of herring spawning in the Fingers area of Liverpool Bay to support a viable commercial roe fishery. Not only does the spawning stock appear to be small, exploitation rates would need to be lower than those for more southerly stocks given the severity of the Arctic environment. Investigations may continue in other areas.

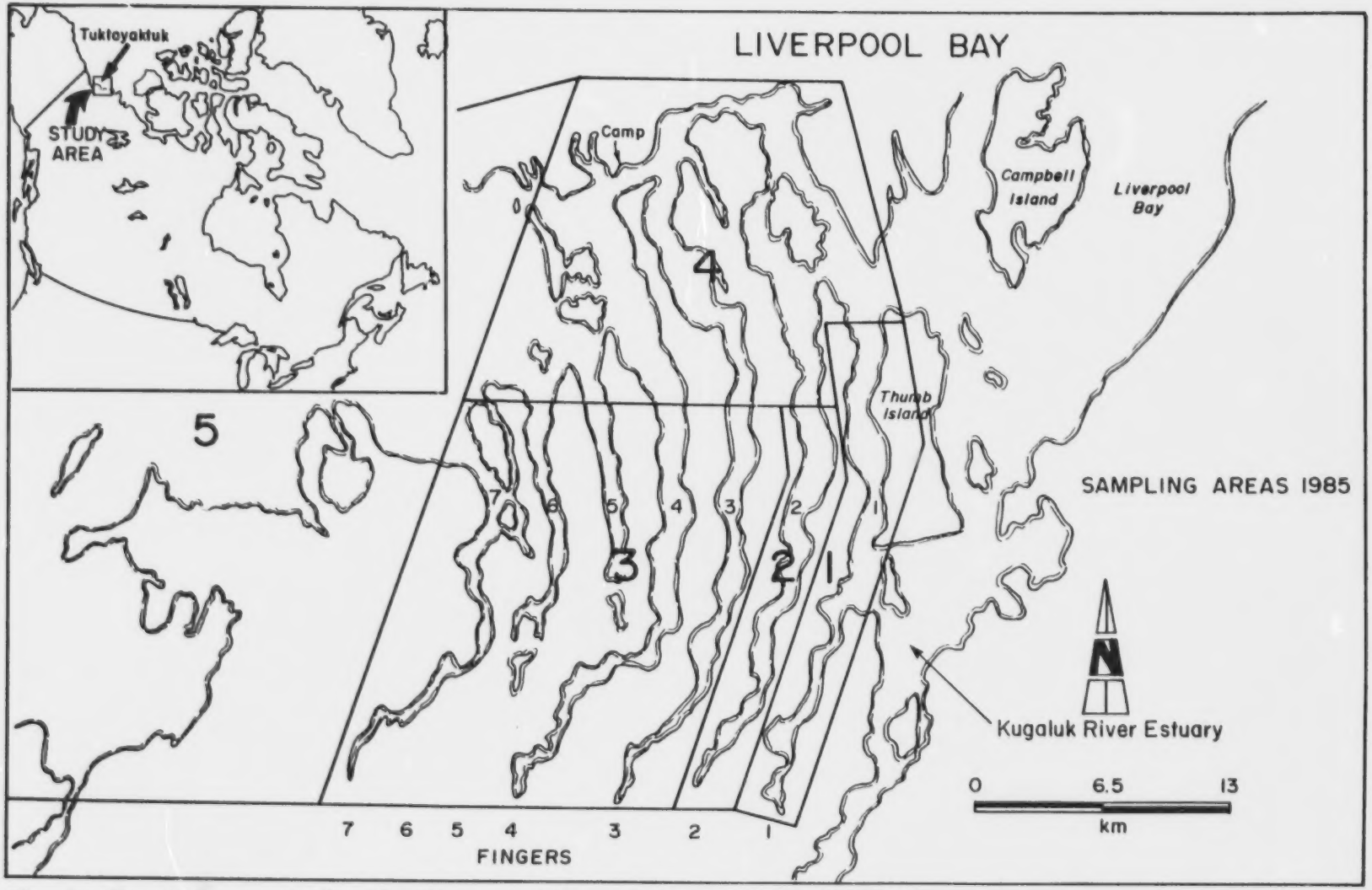

Fig. 1. The study area showing the Fingers in Liverpool Bay, Northwest Territories.

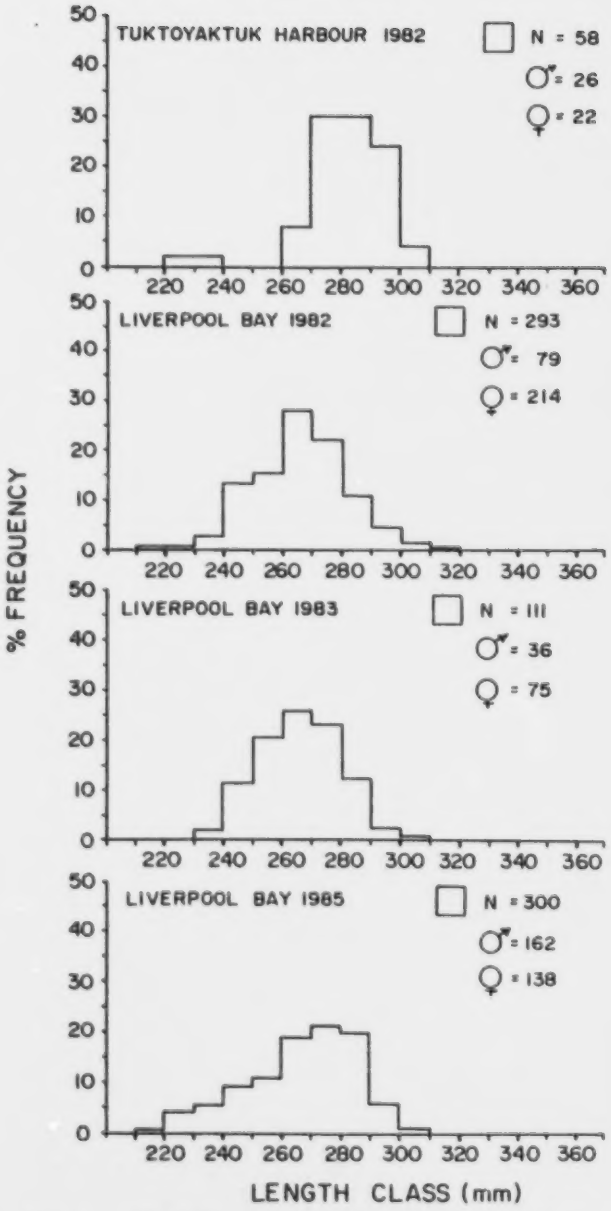

Fig. 2. Length-frequency distribution of Pacific herring spawners from Tuktoyaktuk Harbour and Liverpool Bay.

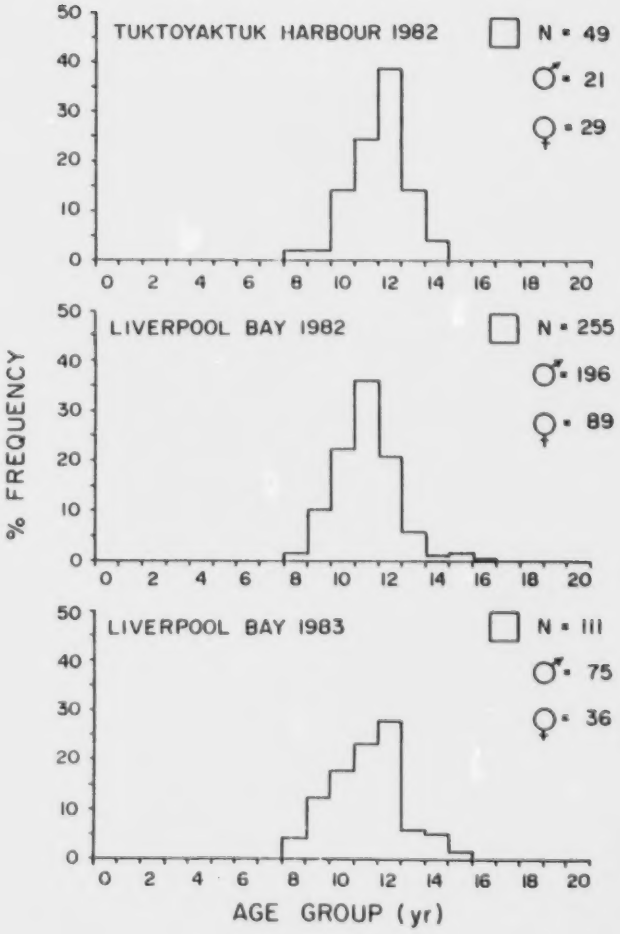

Fig. 3. Age-frequency distribution of Pacific herring spawners from Tuktoyaktuk Harbour and Liverpool Bay.

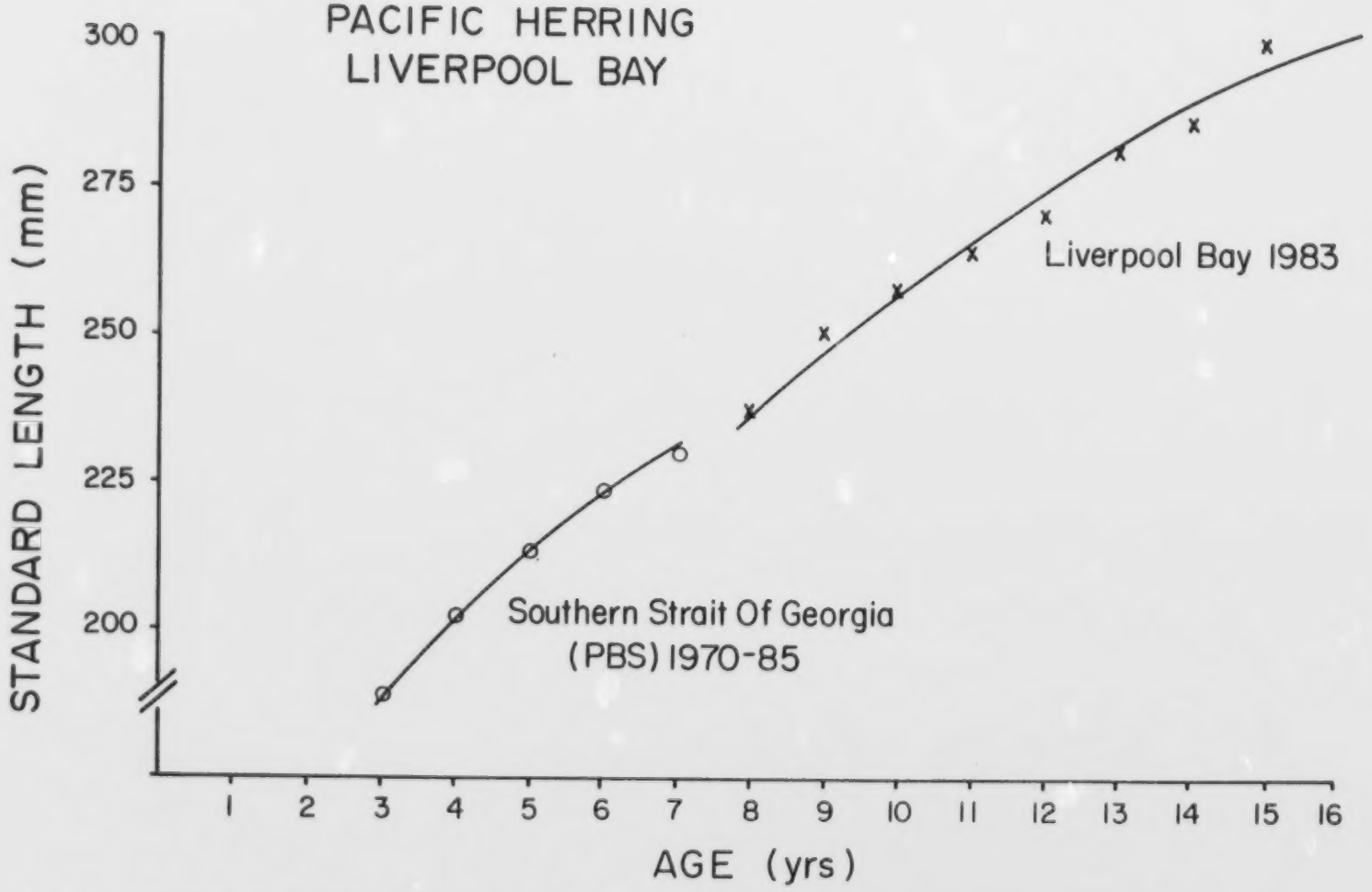

Fig. 4. A comparison of length-at-age between Pacific herring from Liverpool Bay and southern Strait of Georgia.

Preliminary findings of a herring spawn survey conducted in the Fingers Area of Liverpool Bay, Northwest Territories

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The Fingers Area forms a 15 to 20 km wide geographical boundary between Liverpool Bay and the Eskimo Lakes on the southwest side of Tuktoyaktuk Peninsula. A series of narrow, convoluted peninsulas separate seven inlets or "fingers". These fingers, together with the waterways to the north and the approaches to the Kugaluk River to the east comprised nine subregions within the study area (Fig. 1).

Between June 25 and July 20, 1985, six diver/biologists and two local Inuit operated from two base camps, conducting a diving survey of herring spawnings along approximately 500 km of coastline. A total of 766 reconnaissance dredges were conducted to locate 30 herring spawns. Divers conducted detailed surveys to determine the width, shoreline length and intensity of spawn deposition. The Haegele and Schweigert transect method (Schweigert and Fournier 1982) was inappropriate for the small spawn area and low concentration of eggs and substrate. Width transects and quadrat sampling were performed separately. Quadrat sample locations were chosen based on available substrate rather than a random process. Spawn samples were preserved in Gilson's fluid, for later enumeration of herring eggs.

Of the 30 spawns located, 18 were sampled and 12 were not sampled. In four of the unsampled spawns the eggs were hatched out, but egg cases were still present. In these situations spawn area was measured, and spawn intensities were estimated from sampled areas with identical spawning substrates. The remaining eight unsurveyed spawns were located by dredging, but subsequent diver surveys did not locate sufficient eggs to sample.

Other activities conducted throughout the study area included temperature/salinity profiles and the collection of quantitative plankton samples.

Mean egg numbers from all quadrat samples within a spawning were used to estimate the egg density for that particular spawning. Statistical analysis of these data have not yet been conducted. The total area of spawn was estimated to be 66,764 m^2. The estimated total number of eggs within the study area is 3.74×10^8 eggs. This is equivalent to an estimated 5 t of spawning herring. Ninety percent of the eggs were located at the heads of Finger 1 and Finger 2, and within the approaches to the Kugaluk River.

The major spawn substrates consisted of various forms of eroded tundra and two types of aquatic vegetation. The vegetation included a leafy red algae similar to Callophyllis sp. and a vascular seagrass similar to Zostera marina. The depth of herring spawns ranged between 1 m and 4.5 m. Most spawns were between 1 m and 3 m in depth, and were located on shallow sloping sand/mud flats. These depths corresponded with distinct thermoclines

(surface temperatures of 10-12°C) and distinct haloclines (surface salinities of 6-12°/$_{oo}$).

It is estimated that the incubation period for herring eggs in the Fingers Area is 24 days, in contrast to 15 days in British Columbia waters. Herring spawned from early June to July 16. With the exception of Finger 3, spawning within all the subareas was protracted over the duration of the study.

A total of 44 plankton tows were made throughout the study area. Herring larvae were located at the heads of Fingers 2, 4, 5, 6, and 7; in the approaches to the Kugaluk River and within a lagoon located in the northeastern portion of the study area. Based on the developmental stages of the larvae, it is likely that two distinct spawnings in the approaches to the Kugaluk and one spawning in the northern subregion occurred in early June and hatched prior to the survey. The intensity of these earlier spawnings are difficult to estimate given the concentrations of sampled larvae, which ranged between 0.05 and 0.4 larvae$\cdot m^{-3}$.

Based on our findings, it is difficult to estimate with much confidence the exact size of herring stocks which spawned in the Fingers Area. Herring may have spawned outside of the study area; and herring may have spawned prior to, or after the study period. This study has provided a great deal of useful biological information associated with herring spawning behaviour in the Fingers Area. This information can be used by fisheries managers to further investigate herring stocks in the area.

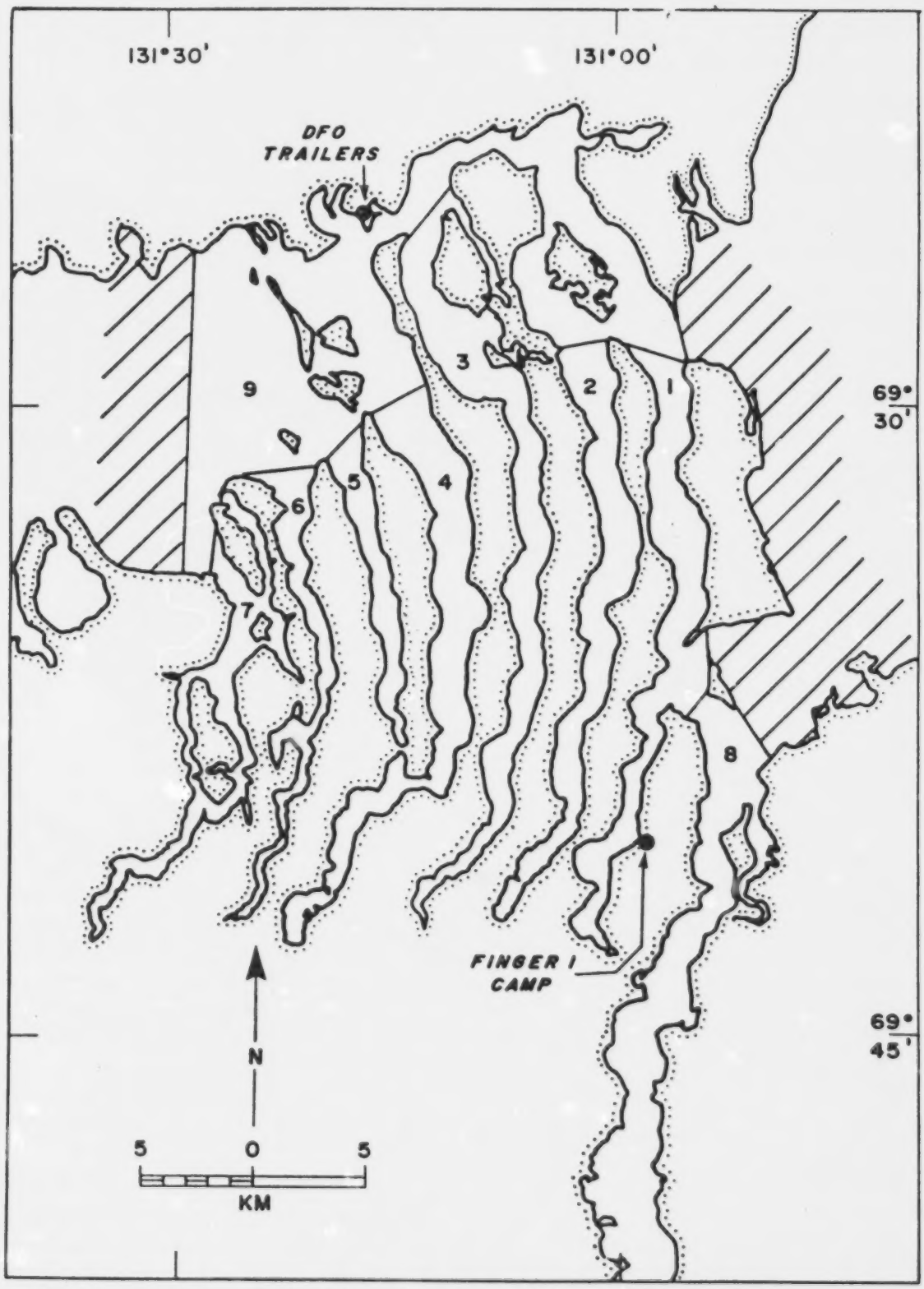

Fig. 1. Location of the nine subregions within the study area.

Evaluation of certain aspects of B.C. herring stock dynamics

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INTRODUCTION

The 1978 Aberdeen Symposium on management and assessment of pelagic fish stocks reached a number of conclusions regarding why pelagic stocks are particularily vulnerable to fishing and overexploitation (Saville 1978). Since then many of the conclusions reached have been further substantiated for additional pelagic stocks, and conservative management strategies developed for a number of them (see for example, Brett 1985). Two of the conclusions of the Aberdeen Symposium are examined in this paper to determine their significance in the dynamics of B.C. herring stocks and consequently their importance to management strategies. The first hypothesis examined is that the left hand limb of the stock-recruit relationship is particularily steep in pelagic species leading to reduced recruitment associated with low spawning biomass. The second hypothesis examined is that natural mortality is density dependent which has been suggested to result from increased levels of predation as stocks decline.

An age-structured model (Fournier and Archibald 1982) has been used for stock reconstructions and forecasts of B.C. herring stocks since 1982; the model incorporates spawn information obtained from fishery officer spawn surveys and uses a maximum likelihood function to estimate all model parameters simultaneously. Spawn-recruit parameters are estimated using a Ricker forumulation. Separate model analyses incorporating an additional biomass dependent natural mortality parameter are used to investigate the assumption of density dependent natural mortality. Results presented are from the stock reconstructions used for the 1985 assessments and forecasts (Haist et al. in prep); the model is described in detail in that assessment document.

For stock assessment and management purposes, seven major herring stocks are recognized on the B.C. coast. These include three northern stocks - Prince Rupert district, Queen Charlotte Islands (Skincuttle to Selwyn inlets) and the central coast; and four southern stocks - the northern and southern Strait of Georgia, and the northern and southern west coast of Vancouver Island.

RESULTS

Spawning trends, that is, the observed spawn index and the spawn predicted from escapement as estimated by age-structured analysis, are shown in Figure 1 for all stock groupings. The stock reconstructions follow the

general trends in the spawn index but do not adhere closely to the annual variations in this index. This results from low weighting on the spawn information in the model (Haist et al. 1985). The spawning trends show that the stocks have fluctuated dramatically through the 35-year time series and all were at record low levels at the time the fishery was closed in 1968. The stock declines and subsequent closure of the fishery has been attributed to recruitment failure combined with recruit overfishing (Hourston 1978).

Annual estimates of spawn, recruitment, and the estimated spawn-recruit relationships assuming a Ricker parameterization are shown in Figures 2a and 2b. All stock groupings, with the exception of the west coast of Vancouver Island, indicate below average levels of recruitment and well below average levels of spawn for the period 1965-1969. The estimates for these years are the primary determinants of the left hand limb of the spawn-recruit relationships. However, because the years of low spawning stock are consecutive the low recruitments may result from a multiyear environmental trend rather than low spawning levels. With the exception of the Queen Charlotte Islands stock there are few years other than the 1965-69 period which support the hypothesis that low spawning stocks result in below average recruitment.

The spawn-recruit relationships also indicate a decrease in average recruitment at high spawn levels. This is particularily evident in the north coast stocks where all good year-classes arise from intermediate spawning stocks. Four particular year-classes which are substantially above average resulted from intermediate spawning levels in all stock groupings. These are the 1951, 1956, 1972, and 1977 year-classes (1977 is exceptional in northern stocks only). Obtaining this level of synchrony for four of the thirty-two recruit estimates suggests that at least occasionally global environmental factors, affecting the entire B.C. coast, are important in determining year-class strength.

The variability in year-class size of a stock is a measure of the stability of that stock, that is, high variability in recruitment will lead to greater stock fluctuations. Coefficients of variation of year-class size for Atlantic herring range from 0.5 to 0.9 normally, however stocks at the extreme of the distributional range may have greater variability (Doubleday 1985). Coefficients of variation of recruitment range from 0.54 to 1.34 for B.C. herring stocks with higher variabilty in the north coast stocks (Table 1). Because the stock groupings for the Strait of Georgia do not reflect the reduction fisheries, that is, a high proportion of the catch in the southern strait was destined to spawn in the northern strait, a more reasonable stock grouping for estimating recruitment variability is a combined Strait of Georgia stock. There may be a similiar problem with data from the west coast of Vancouver Island. For this reason coefficients of variation of recruitment are also presented for the entire Strait of Georgia and the west coast of Vancouver Island. These show a clear trend for higher year-class variability in the north coast stocks than in these combined south coast ones. However, fish tend to mature at older ages in north coast stocks as shown by the difference between age 3 and older escapement and spawning estimates (Fig. 3). This will tend to stabilize spawning levels in northern stocks as large cohorts mature and recruit to the spawning stock over a number of years.

The stock reconstructions incorporating the assumption of density dependent natural mortality performed substantially better than the general runs, that is, they had lower objective function values (Table 1). In all stock groupings the natural mortality estimates were inversely related with biomass which is consistent with the hypothesis that predation mortality increases as herring biomass decreases. The patterns of natural and total mortality, expressed as the proportion dying through the year are shown in Figure 3 for two stock groupings. Although including the assumption of density dependent mortality does not substantially affect the estimates of total mortality for these stock reconstructions, the estimated increase in natural mortality as stocks decline may be a significant factor in stock dynamics causing faster and more severe declines.

CONCLUSIONS

1) Recruitment may be related to the stock's reproductive potential at both low and high spawning levels; the best recruitments have been observed at intermediate spawning levels.
2) Variability in recruitment is higher in northern B.C. stocks than in southern ones, however, because recruitment to the spawning stock occurs over a number of years, there is some compensation to stabilize spawning levels.
3) Age-structured stock reconstructions support the concept of density dependent natural mortality (depensatory). This may be a critical factor in stock dynamics at low stock levels.
4) Four of thirty-two years show recruitment well above average in most B.C. herring stocks, indicating coastwide environmental factors may be important in determining recruit strength in some years.

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Table 1. Parameter estimates from age-structured model analysis for B.C. herring stocks.

Stock grouping	Range of estimated instantaneous natural mortality rates	Objective Function Value		Coefficient of Variation for recruitment
		constant natural mortality	density-dependent natural mortality	
Skincuttle-Laskeek	0.14-1.28	704.1	607.3	1.34
Prince Rupert District	0.25-0.73	943.8	915.8	0.85
Central Coast	0.33-0.60	524.3	511.6	0.84
Strait of Georgia				
- northern	0.27-0.86	687.4	594.6	0.54
- southern	0.36-0.53	728.3	634.0	0.80
- combined				
West coast Vancouver Island				
- northern	0.30-0.59	758.4	652.7	0.57
- southern	0.10-1.50	522.4	365.0	0.75
- combined				

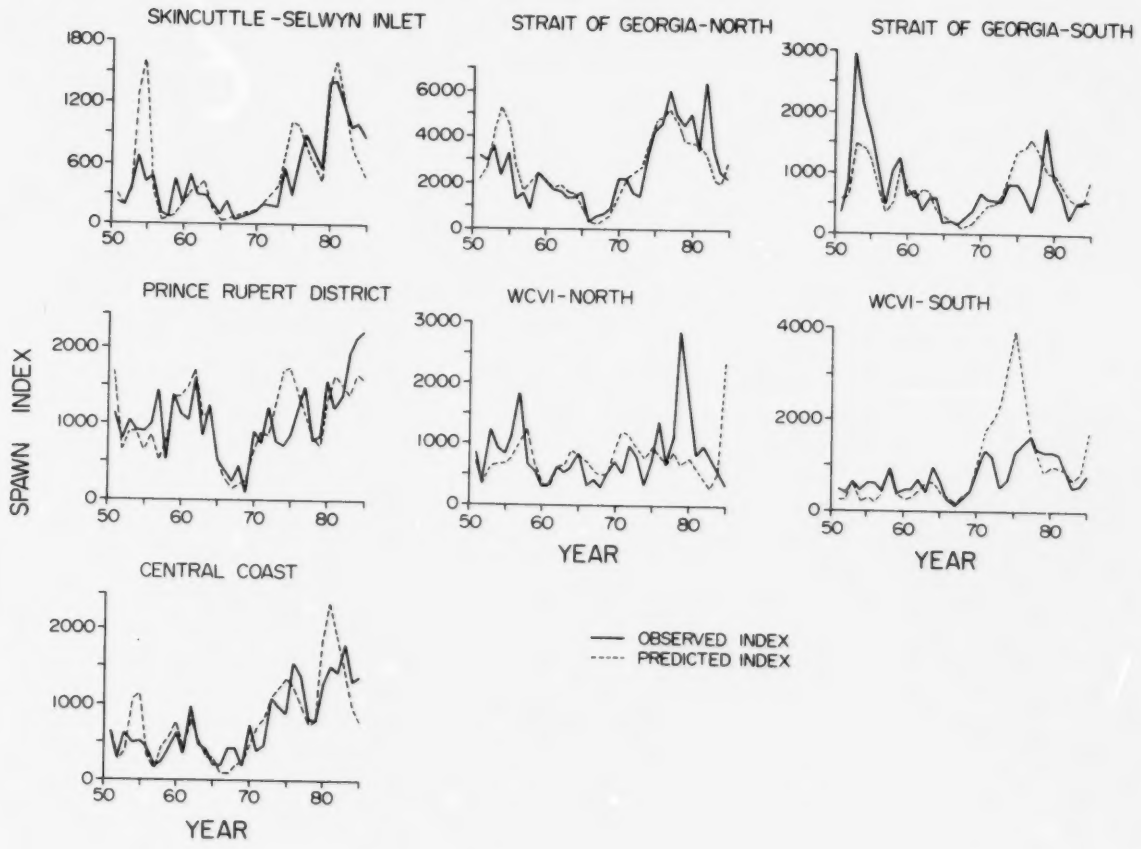

Fig. 1. Observed and predicted spawn indices from age-structured model stock reconstructions for B.C. herring stocks.

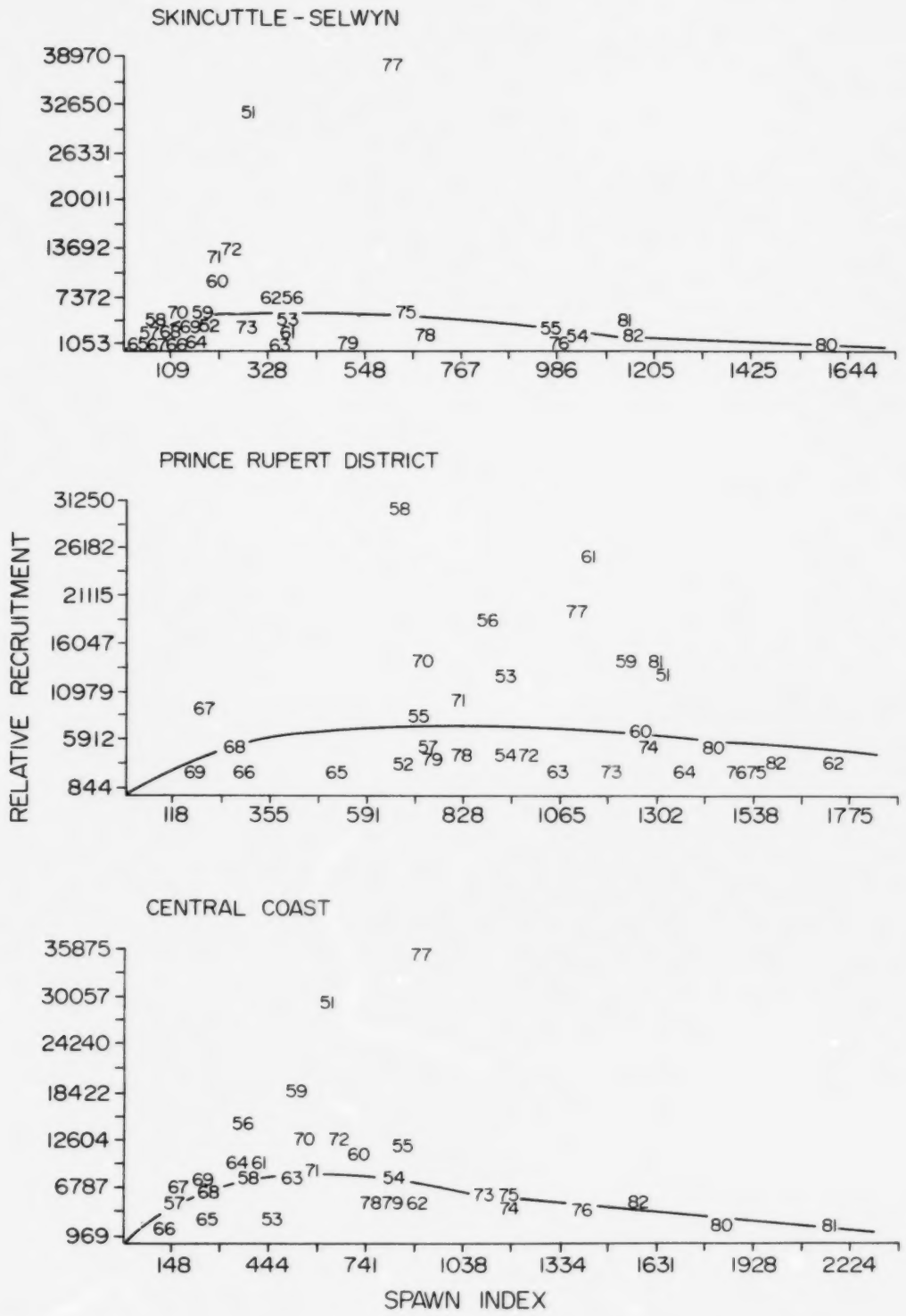

Fig. 2a. Annual spawn and recruit estimates, plotted by year-class, and estimated Ricker spawn-recruitment relationships for northern B.C. herring stocks.

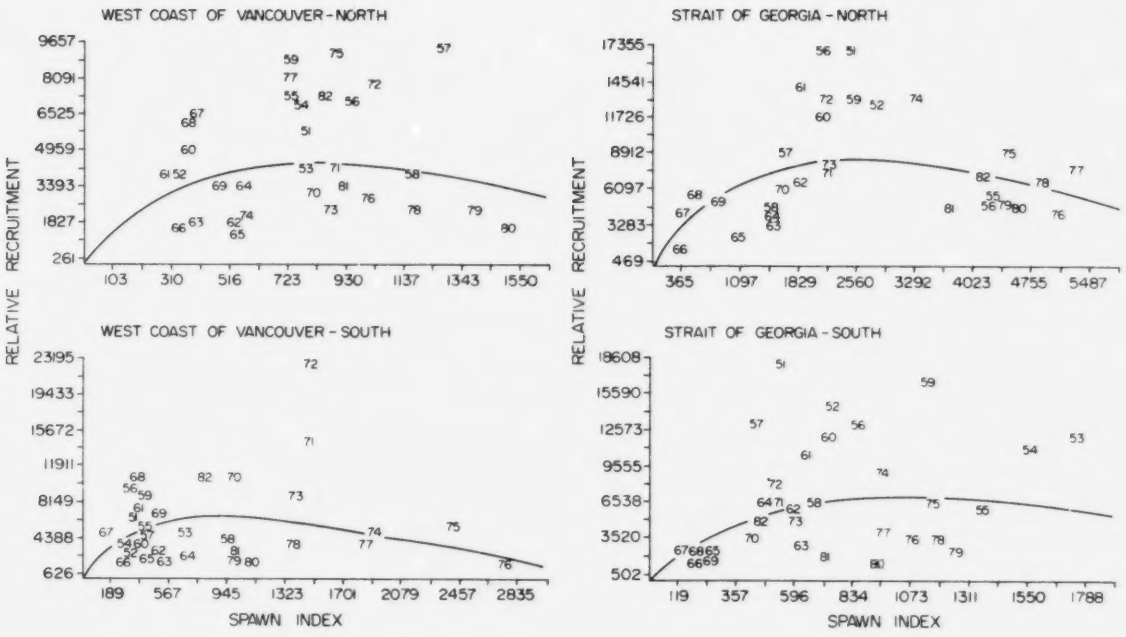
WEST COAST OF VANCOUVER - NORTH
STRAIT OF GEORGIA - NORTH
WEST COAST OF VANCOUVER - SOUTH
STRAIT OF GEORGIA - SOUTH
RELATIVE RECRUITMENT
SPAWN INDEX

Fig. 2b. Annual spawn and recruit estimates, plotted by year-class, and estimated Ricker spawn-recruitment relationships for southern B.C. herring stocks.

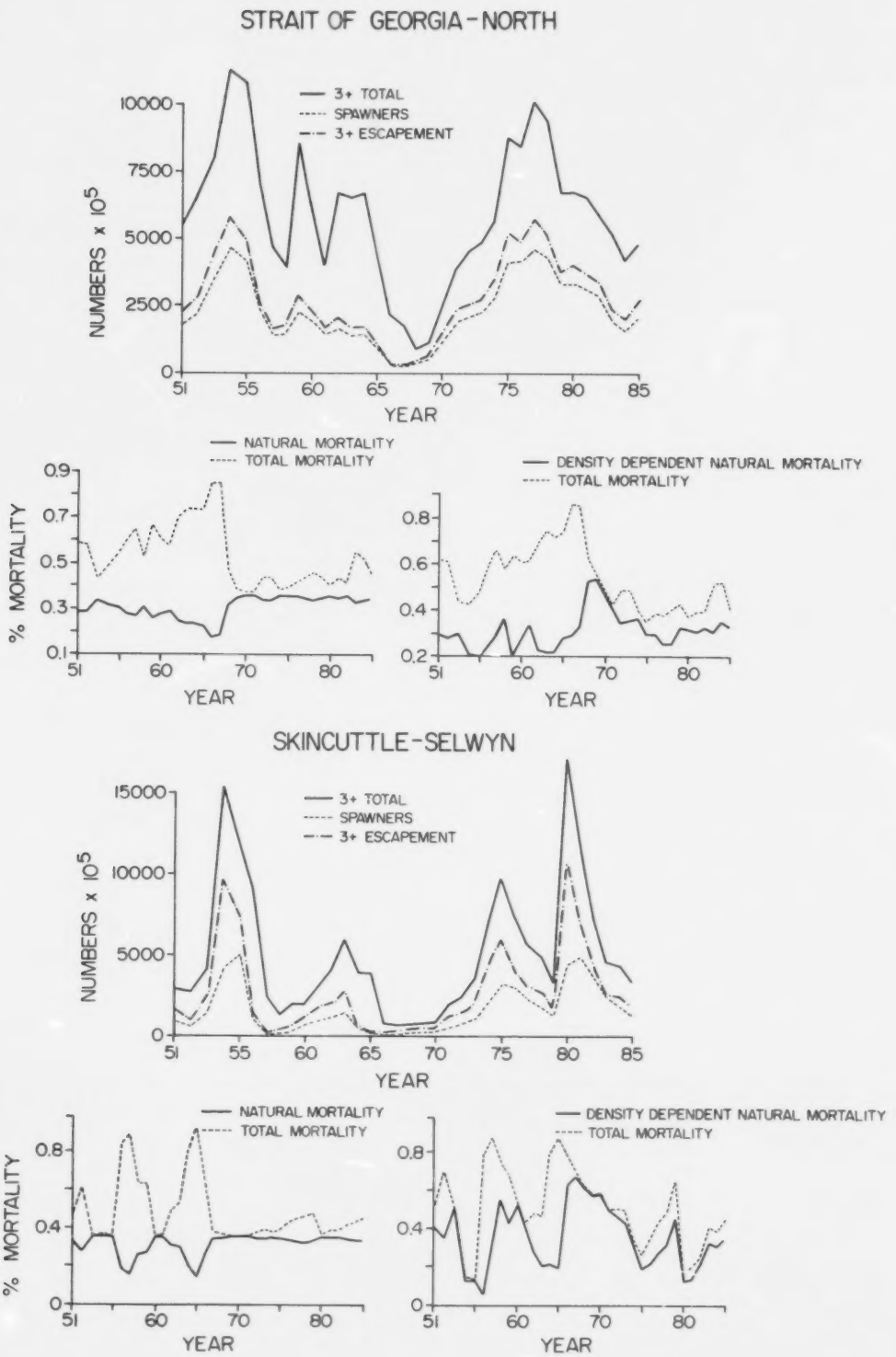

Fig. 3. Estimates of total (3+) stock, spawning stock, and escapement (3+) and mortality estimates from constant and density dependent stock reconstructions for two B.C. herring stocks.

Current status of Puget Sound herring stocks

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DATA SOURCES

The chief stock assessment tool now used by WDF is the grapple-method herring spawn survey. About half of the 20 or more distinct herring spawning grounds are surveyed annually, including all larger stocks (Fig. 1). Spawn surveys are conducted on a biweekly-to-twice weekly basis, depending on information needs. Escapement estimates are arrived at by careful charting of the lineal extent and varying intensity of each spawn patch, and application of spawner-per-intensity-mile criteria based on an estimated 544 t of escapement depositing a mile of "medium" spawn (about 0.7-1.7 egg layers). Spawn samples are regularly taken for estimation of spawning times and detecting superimpositions of spawns. Spawn patch widths are not considered except in those cases (i.e., Drayton Harbor, Fidalgo Bay) where spawning commonly takes place over broad two-dimensional expanses of vegetation bed. Most Puget Sound herring spawning occurs in February and March, with our largest single stock, in the southern Strait of Georgia, spawning from mid-April to late May.

Additional stock assessment data is obtained from selected areas by hydro-acoustic surveys (using real-time echo integration techniques) coupled with simultaneous midwater trawl sampling of those pelagic organisms present. These surveys are now conducted in three areas: Bellingham Bay (overwintering mixed stocks), southern Puget Sound (overwintering mixed stocks), and southern Strait of Georgia (single stock during roe fishery).

PUGET SOUND HERRING SPAWNING GROUNDS

Puget Sound spawning habitats are of two basic types. The vast majority of the total acreage is comprised of a largely subtidal soft-bottom plant community dominated by eelgrass (Zostera) and a red alga (Gracilariopsis). In some areas (Discovery Bay, Kilisut Harbor, Port Gamble, Port Orchard) spawning will also occur just offshore of these beds, on the amassed tubes of the polychaete worm Phyllochaetopterus, at depths of -9 to -15 m or more. The other habitat type occurs on the exposed boulder/cobble shores of the southern Strait of Georgia. Herring spawn deposition is commonly intertidal in this area, on the diverse community of rocky-shore algae. Here Fucus, Sargassum, Laminaria, Desmarestia, Prionitis, Odonthalia, and Botryoglossum as well as Zostera, are common spawn substrates.

STATUS OF SELECTED STOCKS

There are about 24 distinct herring spawning areas in the Puget Sound region, nearly all of which appear to be used annually. They have been

tacitly presumed to be separate stocks. However, the likelihood of shared overwintering grounds, similar spawning times, close proximity of spawning grounds, and potential for mixing and interchange of juveniles would suggest that there may be only about half that number of "stocks" or less, were the definitions of D. Hay (in this publ.) and others applied. An important data gap for Puget Sound herring is the lack of spawning ground-specific biological samples for age structure and stock separation analysis.

In central Puget Sound during the 1980-1985 period, the pooled estimated spawning escapement for an array of the larger stocks appeared to be stable or perhaps declining slightly (Fig. 2). The decline in the last two years was largely due to record low escapements to Discovery Bay and Quartermaster Harbor. Although negative El Niño effects on herring are being reported throughout the Pacific coast, the impact on resident Puget Sound stocks might have been minimal, since it appears that warm waters did not intrude into Puget Sound proper. The Quartermaster Harbor herring population is thought to contribute to the year-round adult herring stock that inhabits the Tacoma Narrows area. Discovery Bay herring, however, probably always reside outside of Puget Sound in the Strait of Juan de Fuca and could have been impacted.

In the southern Strait of Georgia, the late-spawning roe-fishery herring stock continues to decline in biomass, in spite of 5 years without a fishery (Fig. 3). This decline seems to be paralleling similar declines in herring stocks of adjacent Canadian waters. Although currently in a depressed condition, this stock remains the state's largest and will continue to be afforded significant investigative effort. Elsewhere in this publication can be found summaries of other biological studies involving this stock: P. Dygert (population biology, hypotheses for mechanisms for decline), D. Hay (winter spawner/spring spawning stock separation), W. Palson (predation/egg loss studies), and T. Keeghan (dispersal of herring larvae).

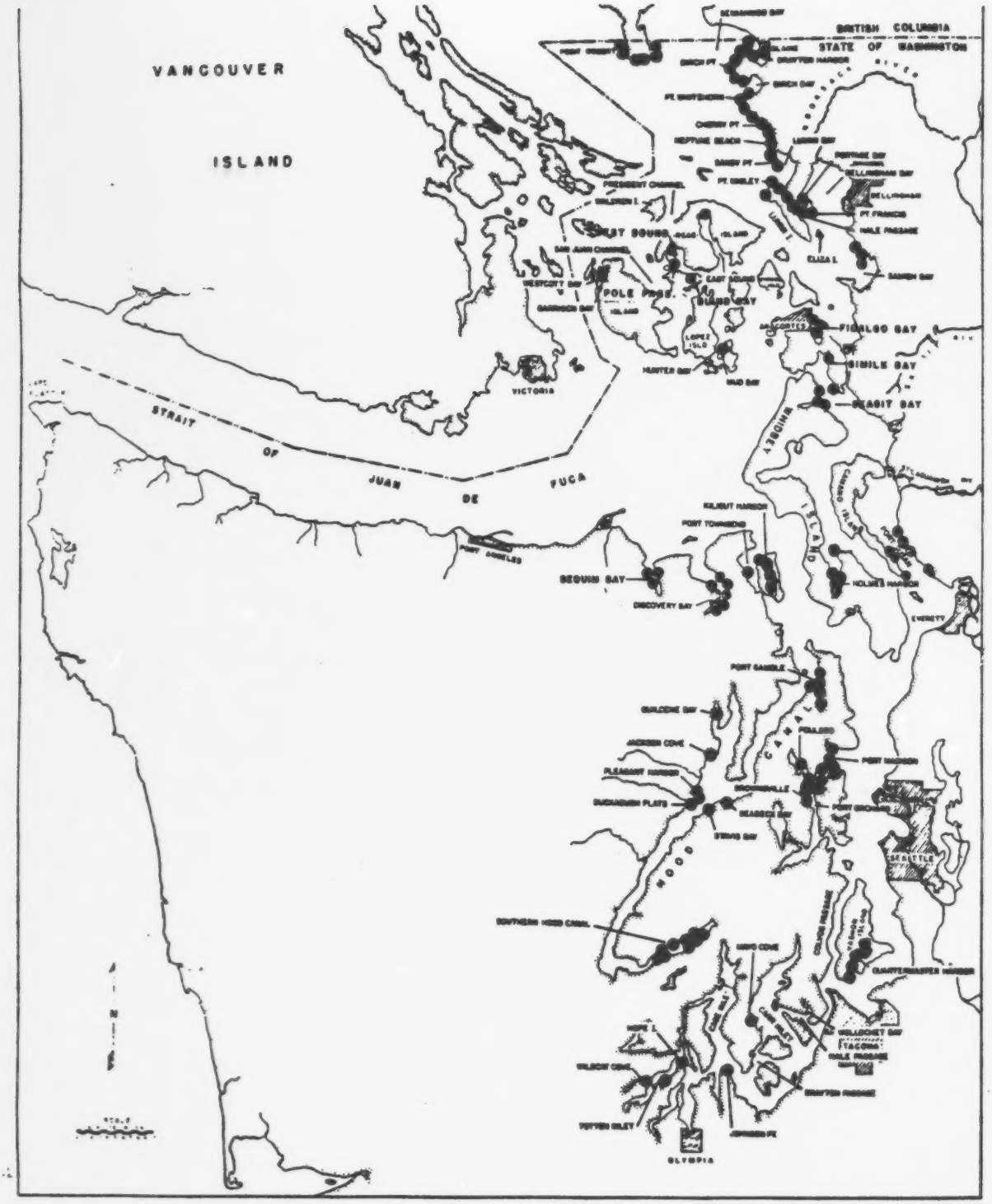

Fig. 1. Pacific herring spawning grounds in the Puget Sound region.

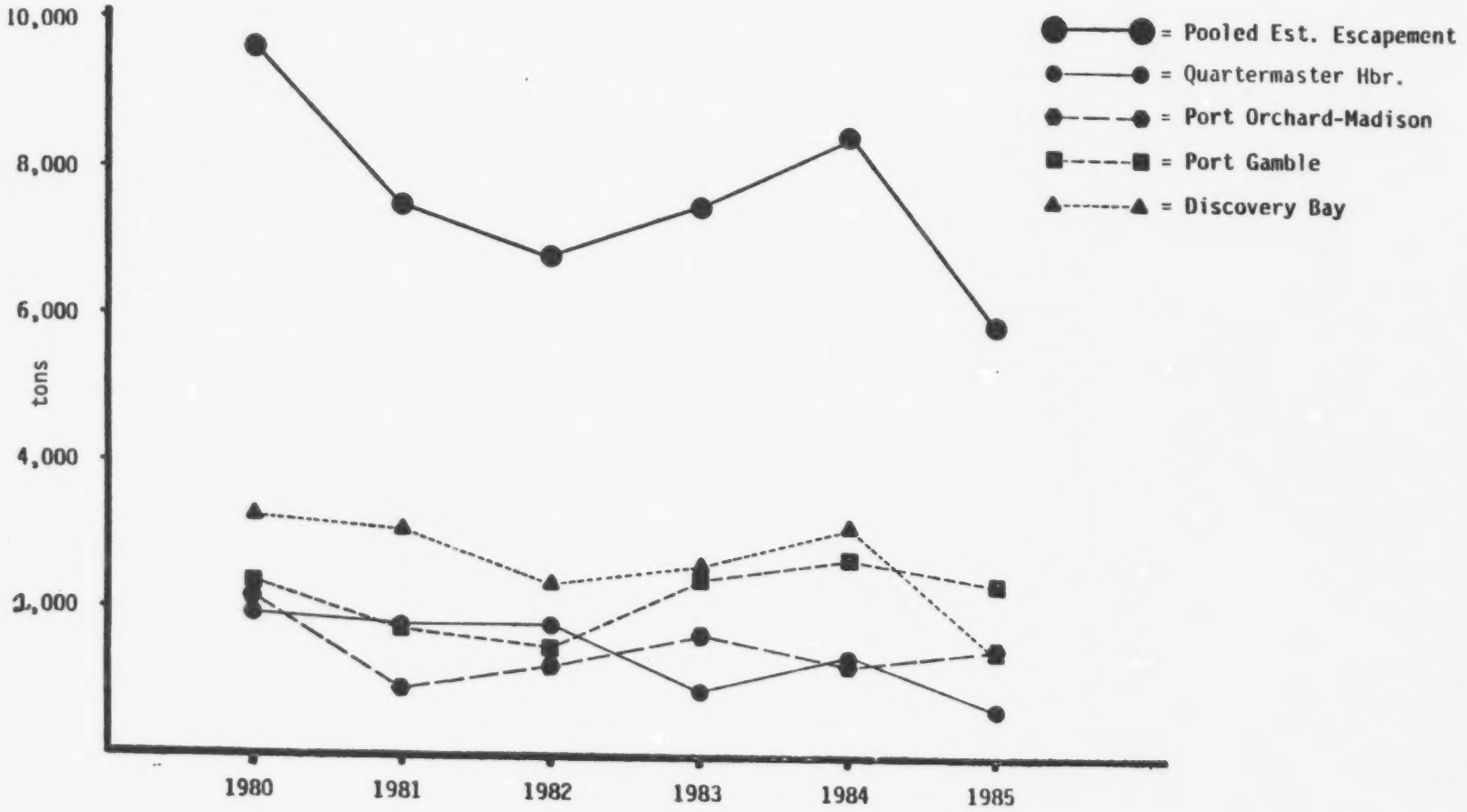

Fig. 2. Estimated Herring spawning escapement biomass for some larger Puget Sound stocks, 1980-1985.

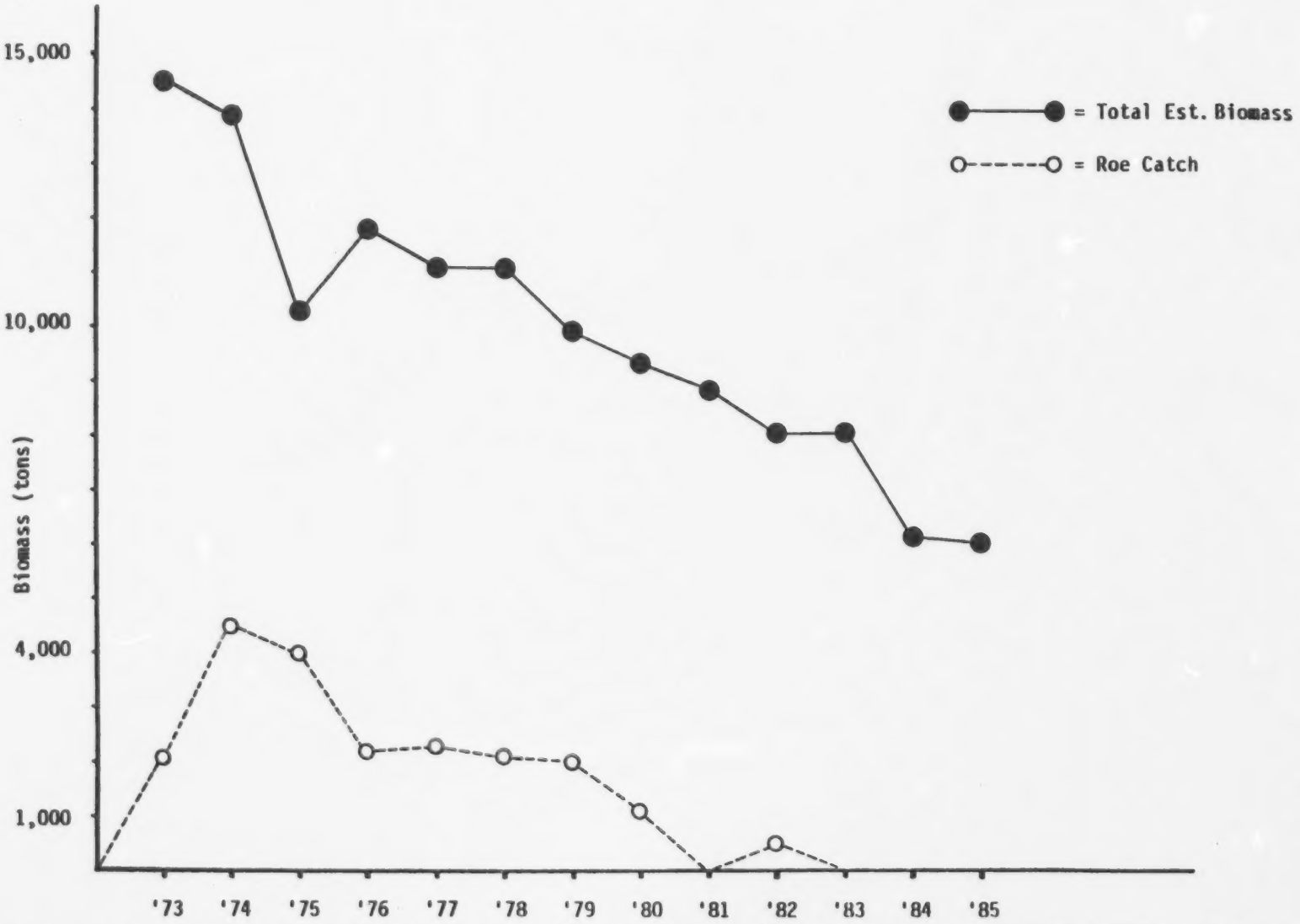

Fig. 3. Estimated spawning Biomass and roe catch for U.S. Strait of Georgia herring stock (Whatcom Co., WA).

Age and growth of Pacific herring in San Francisco Bay

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The Pacific herring supports a roe fishery in the San Francisco Bay that has yielded an average of 5262 t during the last 10 seasons. The California Department of Fish and Game manages the fishery by quota based on spawn escapement estimates and commercial catch from the previous season. Life history parameters are essential to aid in properly managing this valuable resource.

Age and growth data for Pacific herring stocks from San Francisco Bay are available from three primary sources: (1) a research program, conducted by myself and Tom Moore since late 1981, has sampled most spawning schools for length, weight, and age composition throughout the November to March spawning season; (2) Jerry Spratt, Department of Fish and Game, Monterey, has collected samples for length, weight, and age composition from the purse seine, lampara net, and gill net fisheries each year since 1983; (3) the Department of Fish and Game's Bay/Delta Project, Stockton, has incidentally collected young-of-the-year (YOY) and juvenile herring with a midwater trawl in San Francisco Bay since 1980.

Body length (BL), the Department's standard measurement for herring (Spratt 1981), was determined to the nearest mm from the tip of the snout to the end of the pigment underneath the last column of scales on the caudal peduncle. Herring were aged using otoliths. In addition to obtaining samples from the fishery, our research project uses 5-panel, 15 m long variable-mesh gill nets and a 3.7 x 3.7 m mouth opening midwater trawl to sample herring schools from a 7 m boat. Since 1973 the Department has measured more than 40,000 and aged more than 12,000 herring from San Francisco Bay.

The characteristic growth pattern on otoliths from San Francisco Bay herring begins with a relatively wide first-year growth zone, occasionally containing checks or false annuli which may relate to a change in habitat when YOY herring leave the bay and enter the ocean in the summer. Concentric growth zones in succeeding years become more narrow until the fourth year. Beginning with the fourth year, growth zones are approximately of equal width. The El Niño event of 1982-83 decreased growth rates of central California herring in 1983 and was evident in otolith growth as well.

Age composition of San Francisco Bay spawning schools changes during the season. Schools in November and December consist primarily of 4- to 7-yr-old herring and gradually shift to a predominance of 2- to 5-yr-old fish by late January or early February. The latter age groups comprise the bulk of our spawnings stocks (Table 1). Eight- and 9-yr-old herring generally contribute less than 1% by number to the total spawning stocks, and only one 10-yr-old herring has been aged from samples. We have seen only one relatively weak year class recruited to the fishery in the last 6 years, that being the 1981 year class.

San Francisco Bay herring are fast growers through their first two years of life and, by their fourth year, increase in BL by 10 mm per year or less (Table 2). Herring greater than 230 mm are rare in our samples, and the largest fish measured from San Francisco Bay since 1973 was 244 mm. The El Niño event had a pronounced effect on growth of herring sampled during the 1983-84 season. Weight-at-age data for this period showed a decline from historic values of from 10 to 20% followed by a remarkable recovery the following season (Table 3). Length-at-age values for most age classes during 1983-84 were also below long-term averages (Table 2). Calculated K and L_{∞} values, using Ford-Walford plots, ranged from .35 to .52 and from 203 to 231 mm, respectively.

Length frequency distributions of YOY and juvenile (1+yr-olds) herring generally are widely separated (Figs. 1, 2). YOY fish sampled from April to August usually range from 30 to 70 mm BL, while juveniles range from 120 to 160 mm. Monthly histograms from trawl samples near the Golden Gate Bridge (GGB) (Figs. 1, 3) show a gradual increase in modal BL from April to July. However, samples from farther inside the bay (Fig. 1, not labelled GGB) sometimes show a decrease in modal BL from month to month. This is due to the availability of YOY herring to the trawl as those fish from a particular spawn reach a minimum size vulnerable to capture. Spawning occurs at approximately 10-14 day intervals over a five-month period and, as YOY fish grow, they move towards the entrance to the bay (GGB) and eventually leave. Thus, growth modes may shift to the left and it would be then not valid to infer growth from modes.

However, 70% of our biomass during the 1984-85 season spawned during a six-week period in January and February. Modes from large samples, particularly in May, June, and July, most likely reflect the growth of the majority of YOY herring. In May, the mode was 42-43 mm, in June 50-51 mm, and and in July, the mode was 60-61 mm, a growth rate of approximately 10 mm per month. This is consistent with a mean length of 120 mm from 12-month-old herring, as determined in samples from previous years. Differences in first and second year growth between year classes may be seen in a comparison of May samples from 3 different years (Fig. 2). In 1983 there was a relatively small gap in length distribution between the two year classes, probably due to the effect of El Niño conditions on juvenile growth before these 1+yr old fish return to the bay in the spring. First-year growth may be directly related to bay temperatures during time of spawning and early development. Mean bay temperature between December 1981 and February 1982 was the coldest of the last four seasons and may have reduced growth rates. Thus, the combination of bay temperature and El Niño conditions most likely resulted in the poor growth exhibited by the 1982 year class in May 1983 samples. On the other hand, the 1983 year class, shown here as juveniles in May 1985 (Fig. 2), experienced relatively warm bay temperatures and normal oceanic conditions, resulting in exceptionally good growth.

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Table 1. Total percentage age composition by weight for San Francisco Bay herring.

	Age (yr)							
Season	1	2	3	4	5	6	7	8
1983-84	-	42.9	11.9	17.7	19.4	6.6	1.4	0.1
1984-85	0.2	20.7	48.8	8.3	7.8	10.5	2.9	0.8

Table 2. Body length-at-age for San Francisco Bay herring.

		Age (yr)									Sample
Season	Data source	1	2	3	4	5	6	7	8	9	size
1973-74 to 1984-85	Spratt	120	161	175	187	195	203	213	215	-	2728
1982-83	Reilly & Moore	123	158	171	188	199	207	215	224	226	2126
1983-84	Spratt	-	152	164	179	188	195	202	-	-	178
	Reilly & Moore	110	153	172	182	194	201	209	214	-	1621
1984-85	Reilly & Moore	133	161	181	190	197	204	209	215	-	1943

Table 3. Weight-at-age for San Francisco Bay herring.

Age (yr)	Historic mean wt (g)	1983-84 mean wt (g)	1984-85 mean wt (g)	Percentage difference past two seasons
2	52.3	47.3	64.1	35.5
3	77.3	68.3	96.5	41.3
4	99.0	81.6	111.2	36.2
5	118.7	99.7	126.0	26.4
6	136.8	111.4	138.1	24.0
7	154.3	127.8	148.8	16.4
8	168.5	135.6	156.1	15.1

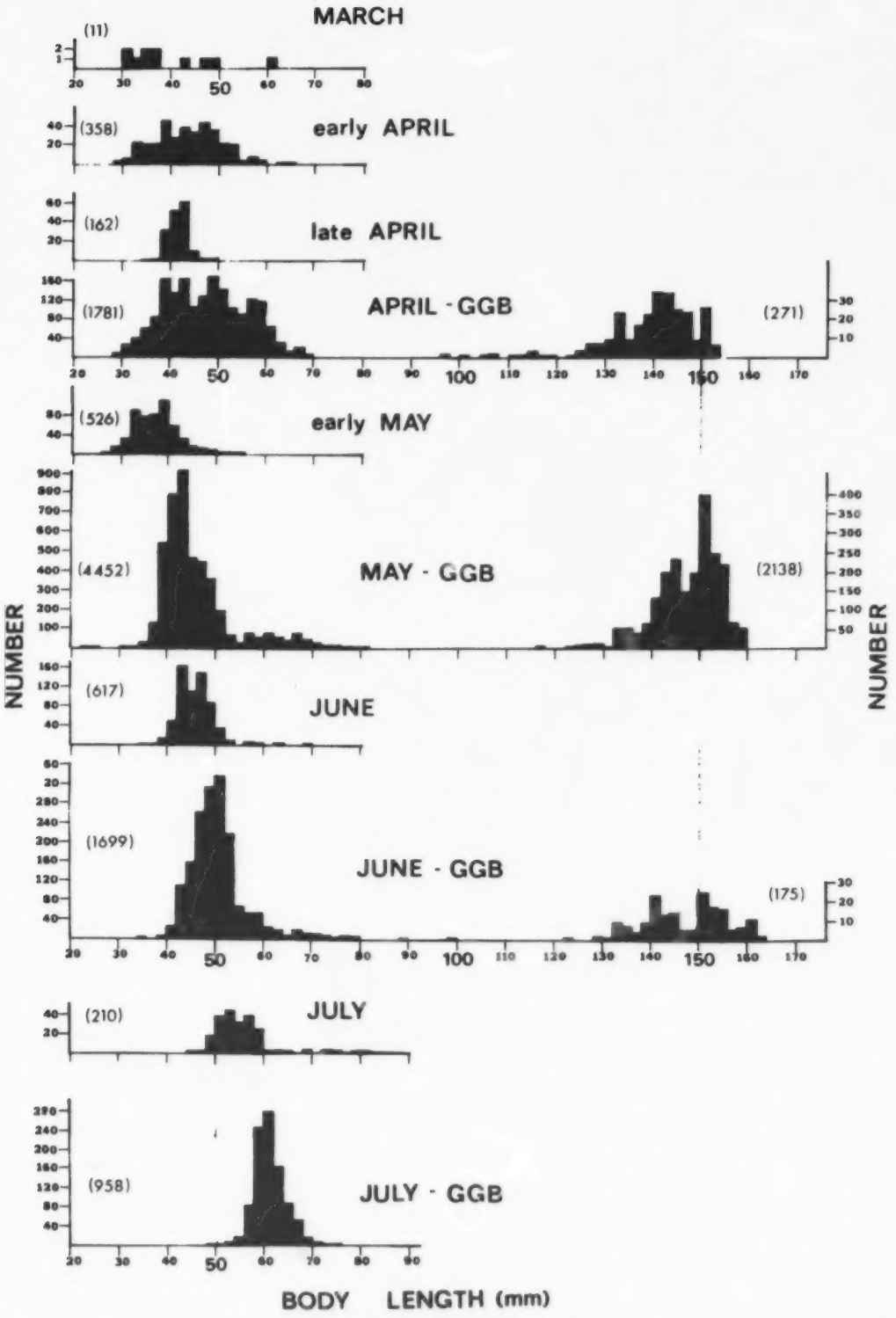

Fig. 1. Number of Pacific herring (2-mm intervals) from midwater trawl samples in San Francisco Bay, March to July 1985.

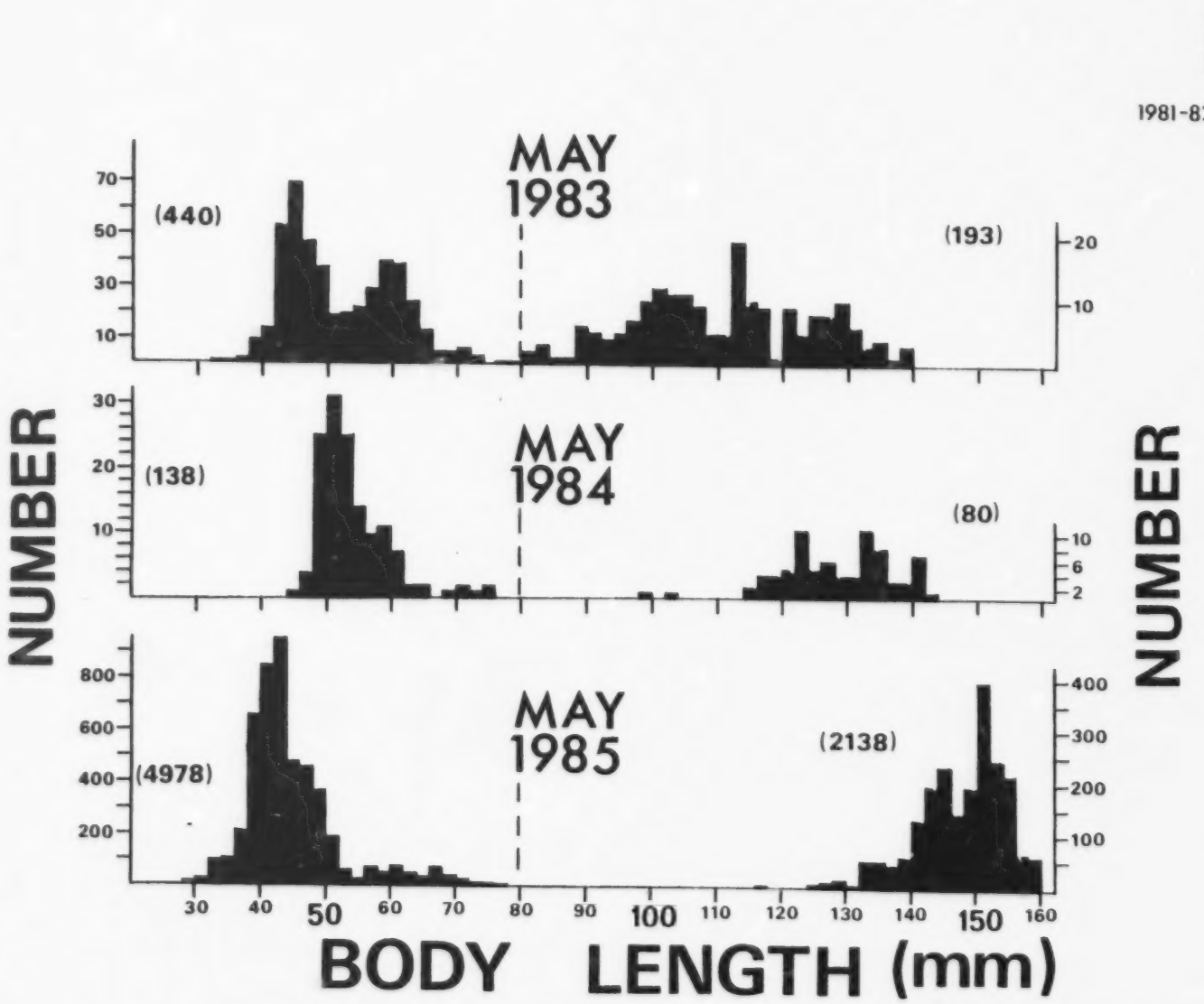

Fig. 2. Number of Pacific herring (2-mm intervals) from midwater trawl samples in San Francisco Bay, May 1983, 1984, and 1985.

Fig. 3. Pacific herring sampling areas in San Francisco Bay.

Early life history of Puget Sound herring

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BACKGROUND AND DATA SOURCE

Early life history studies of Puget Sound herring have been undertaken since 1976 in an attempt to predict year class strengths and abundances of juvenile herring available to salmon-sport bait fisheries, investigate recruitment indices, and gain general knowledge of a potentially important herring life phase of which nothing was known for Puget Sound prior to the start of directed herring work in the region in 1972.

Data sources for the following generalized view included: late-winter-spring plankton sampling in southern Puget Sound (1975-77), hydro-acoustic/midwater trawl surveys in southern Puget Sound (1972-present), and primarily summer surface-trawl surveys throughout Puget Sound (1976-present).

Our current surface-trawl sampling procedure involves monthly June-September surveys, timed to the new moon, during which single 5-minute tows are made at 60+ fixed sites between Carr Inlet (south Sound) and Port Ludlow and Port Susan (north Sound). During a typical summer survey series, roughly two-thirds of such tows will yield samples of at least 100 0+ herring, with various juvenile salmon species and juvenile Loligo squid also common in the catches. Mean monthly catch rates have commonly been in the range of 91 to 907 g of 0+ herring per minute of towing. The trawl has an effective mouth opening of 3.1 x 4.6 m, and is towed at about 2 knots. Procedures have also been developed to allow sampling to depth of 15 m if conditions warrant.

GENERALIZED VIEW OF HERRING EARLY LIFE HISTORY

After hatching in mid-February and March on the various scattered Puget Sound spawning areas, there seems to be limited dispersal of larvae or metamorphosing juveniles through June (Fig. 1). Large June 0+ herring catches are almost always made within a few miles of the spawning areas, and only at near-shore sampling sites. At this time, 0+ herring are scarce on the east shore of the sound and in the inlets of southernmost Puget Sound. June 0+ herring are generally in the range of 35-60 mm SL, with considerable variation between catches. This suggest a tendency for distinct broods of hatchlings to remain discrete up to this time. July surveys tend to show a similar pattern of 0+ herring distribution, with some increase in the degree of dispersal and an increase in mean SL to the 50-70 mm range.

By August, however, there have often been profound changes in the abundance and distribution of 0+ herring inside Puget Sound. Zero-plus herring are now usually quite widely dispersed throughout the survey area

(Fig. 2). They are often found at offshore and mid-channel sites as well as near-shore. High numbers may be encountered from bank-to-bank across the Sound south of Seattle and in the south Sound inlets. By this time of the summer, they are in the 70-90 mm mean SL range. There is usually a gradual cline in length from north to south in the study area, with larger fish to be found in the south. In about half of the years sampled, the high August abundances of 0+ herring inside the Sound cannot be accounted for by the low numbers found the previous two months, and there seems to be large rapid influxes of generally smaller herring into the study area. Although we have yet to catch an influx event in the process of unfolding, it is presumed that the source is north, outside of Admiralty Inlet.

In late September, Puget Sound 0+ herring begin their offshore movement to an overwintering position in deeper water. Large concentrations of 0+ herring occur from October through January in Case and Carr inlets in southernmost Puget Sound, where they commonly mix in varying degrees with overwintering 1+ and adult fish. It cannot be presumed that all of the 0+ herring occurring within the study area move southward into south Puget Sound for the winter. However, it is as yet unknown where else inside of Puget Sound similar concentrations of young fish might migrate.

Although it has been presumed that Puget Sound adult herring are migratory, there is now indication that this is not totally the case. It may in fact be a variable phenomenon for some proportion of these fish. Adult herring have been quite common in our summer surface-trawl catches for the past 2 years, after having been only rarely seen during the first several years of the sampling program, all during a period of stable or slightly declining spawning escapement to the grounds in the region. The relative abundance of 1+ herring (pre-recruits) has likewise been high during these same recent summers. A wide range of variability in migration pattern of Puget Sound herring during their first 2 years of life seems to be a key factor in interpreting the available data.

In our pursuit of possible recruitment indices, there appears to be a positive correlation between the late-summer relative abundance of surface-trawled 0+ herring and the subsequent relative abundance of midwater-trawled 3-year-old fish in the over-wintering adult herring population in southern Puget Sound. We hope to continue the summer surface-trawl/ winter midwater trawl work into future years to accumulate a more adequate data time-series. Correlations with Puget Sound basin climatiological factors will also be investigated.

Fig. 1. Generalized distribution of 0+ herring in June in Puget Sound.

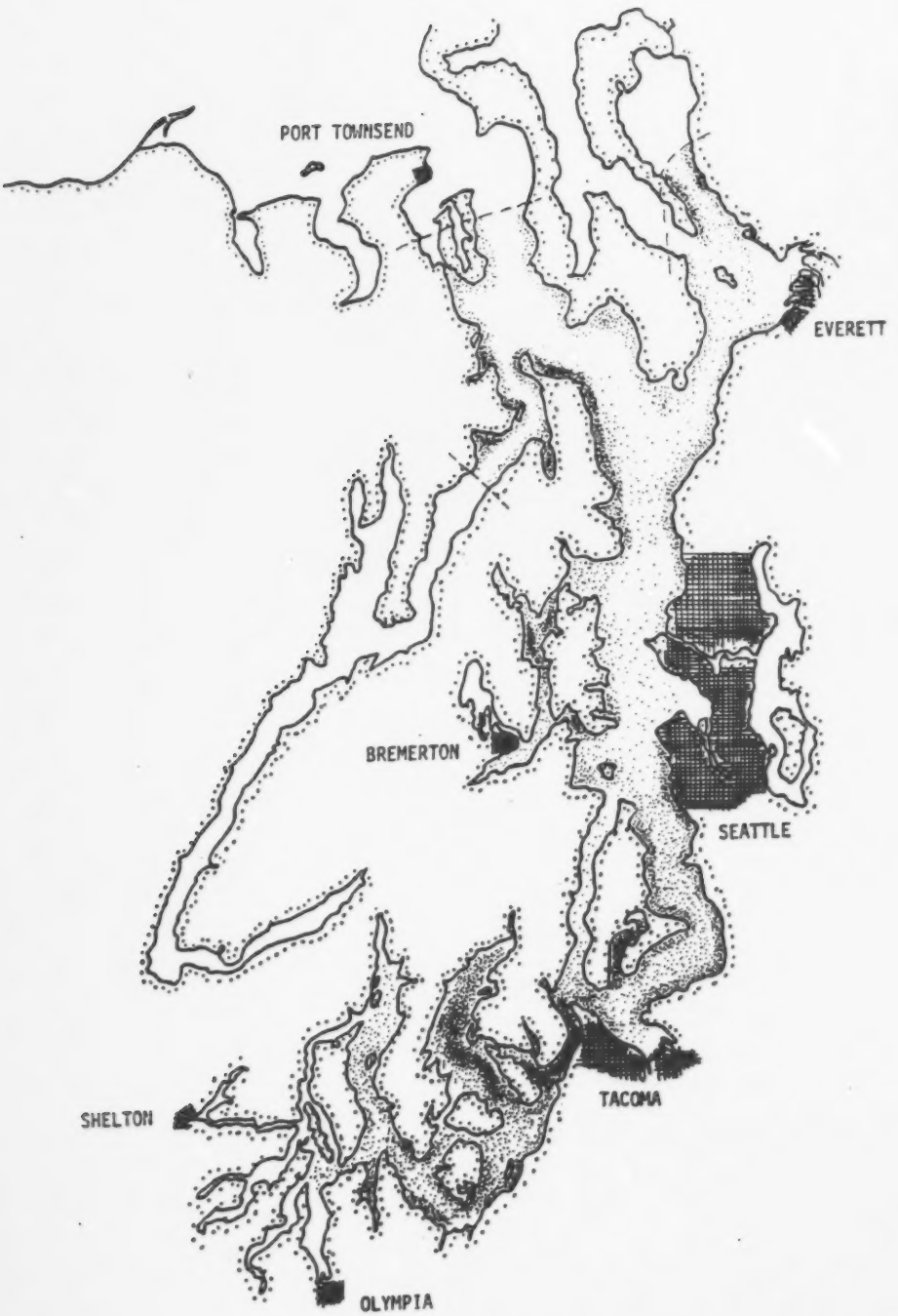

Fig. 2. Generalized distribution of 0+ herring in August in Puget Sound.

Nearshore distribution and growth of Pacific herring larvae (Clupea pallasi) near Birch Point, Washington

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This study was developed out of a concern that existing and proposed industrial development of shorelines containing important Pacific herring spawning grounds might result in significant loss of the resource. Though locations of major spawning grounds in Washington are well known, little information is available describing larval production or dynamics of larval movement off the spawning grounds. The present work is part of a phased study supported financially by Washington Sea Grant and in cooperation with Washington Department of Fisheries (WDF). The primary objectives are: (1) define the spatial and temporal use of the nearshore zone by Pacific herring larvae, and (2) quantify larval cohort abundances in time-series within the study area. A secondary objective is to determine and compare growth rates of several identifiable larval herring cohorts. In order to achieve these objectives, a study design was developed which would enable the investigator to identify individual larval cohorts from discrete spawning waves and to monitor the movement of each cohort through the study area to the offshore waters of the Strait of Georgia. Both the primary and secondary objectives depend on length frequency analysis of larvae from individual stations and station groups.

This study involved sampling the larvae of two stocks of herring separated by temporal and spatial differences in spawning behavior. A winter-spawning stock is apparent from WDF spawning ground surveys which identify the eelgrass beds within and immediately outside the mouth of Drayton Harbor as the primary spawning grounds. Recently, spawn from this early spawning stock was also found on eelgrass beds within Birch Bay. During certain years spawn has also been found in the Canadian waters of Boundary Bay inside from Point Roberts. These areas may be characterized as being relatively sheltered. In contrast, the spring spawning stock (known as the roe-fishery stock) apparently prefers the more exposed shorelines running from Semiahmoo Spit around Birch Point to the northern edge of Birch Bay. In addition, heavy spawning activity occurs south of Birch Bay near Cherry Point. Red algae are apparently the preferred substrate for spring spawners, however eelgrass beds off Semiahmoo Spit have also received heavy spawn during the spring. Although yearly spawner biomass estimates for the winter spawning stock have not been adequately assessed, good records are available for the spring spawning stock. Since 1980, it has been apparent that spawning biomass is in rapid decline resulting in herring roe fishery closures in 1981, 1983, 1984, and 1985.

Sampling effort was initially conducted in 1983 over seven transects throughout the U.S. southern Strait of Georgia under the premise that larval herring were being retained in a counter-clockwise gyre set up by prevailling winds and discharge from the Fraser River. Results from two surveys in late

May and early June suggest that larvae are rearing within the southern Strait of Georgia. Greatest larval abundance was observed at nearshore stations off spawning grounds (up to 104 larvae$\cdot m^{-2}$ surface area). However, of all offshore stations, those stations near the center of the southern Strait contained the larger numbers of larvae (up to 33 larvae$\cdot m^{-2}$). Further, up to four length modes were present at most stations. The fact that newly-hatched larvae (less than 9 mm in total length) were also collected from most stations implies that larvae are being rapidly entrained into the Strait of Georgia.

In 1984, sampling was conducted twice-weekly over a grid of stations extending three miles offshore over four transects and in Drayton Harbor and Birch Bay (Fig. 1). The intent was to confirm the rapid larval movement off the spawning grounds into the offshore region of the Strait. To accomplish this, mean numbers of larvae$\cdot m^{-2}$ were computed for each date by three subareas; Drayton Harbor, Semiahmoo Bay and Birch Bay (Table 1). Cohorts within each subarea were then identified by date using length-frequency analysis. Length modes for Drayton Harbor and Semiahmoo Bay were unique due to the discrete nature of spawning waves and little contamination from other spawning sources. However, this was not the case for the Birch Bay transect. Hence, results are reported only for the former subareas.

Cohort abundances by date are presented in Tables 2 and 3 for Drayton Harbor and Semiahmoo Bay, respectively. The single most abundant larval cohort hatched from the winter spawning stock was first observed on March 19 when 290 and 85 larvae$\cdot m^{-2}$ were collected in Drayton Harbor and Semiahmoo Bay. Next in order of abundance were two larval cohorts from the roe-fishery spawning stock. Larval cohort abundances at the time of first capture (May 21 and May 30) were calculated to be 67 and 20 larvae$\cdot m^{-2}$, respectively, in Semiahmoo Bay. Larvae from the roe-fishery stock were also collected within Drayton Harbor. Of interest is that peak larval abundance in Drayton Harbor generally occurred subsequent to peaks observed in Semiahmoo Bay (Tables 2, 3). Further, during the period of peak larval cohort abundance in Drayton Harbor, average numbers of larvae$\cdot m^{-2}$ in Drayton Harbor were greater than those noted in Semiahmoo Bay. This confirms a degree of larval entrainment into Drayton Harbor. However, the major larval movement is offshore, based on the appearance of peak larval cohort abundances at offshore stations subsequent to peaks observed at nearshore stations.

Generally, larvae surviving from the winter spawning stock remain in Drayton Harbor for at least four weeks, although in reduced numbers. Numbers of larvae from the two major cohorts hatched in Drayton Harbor had declined from 38 to less than 1 larvae$\cdot m^{-2}$ in approximately four weeks and from 67 to less than 1 larvae$\cdot m^{-2}$ in six weeks. The majority of those larvae which were transported out of Drayton Harbor were generally absent from the study area (5 km offshore from the spawning grounds) after two weeks. In contrast, the majority of larvae from the roe-fishery spawning stock had emigrated from the study area by by two weeks after hatching. Within the study area, larval abundances of the two major roe-fishery stock cohorts had declined from 67 to less than 1 larve$\cdot m^{-2}$ and from 20 to less than 1 larvae$\cdot m^{-2}$, both in approximately two weeks after hatching.

Daily percent reductions of numbers of larvae from cohorts within Drayton Harbor averaged approximately 7% while cohorts from the roe-fishery stock declined from within the study area at an average daily rate of 20%. It should be noted that larval mortality probably accounts for the majority of the decline in numbers; however, no attempt was made to partition mortality from total decline within the study area. Also, based on day/night sampling conducted in 1985 (not reported here), larvae greater than 15 mm in length are not as vulnerable to the gear as are newly-hatched larvae. Therefore, results from samples taken about three weeks after hatching are presumably negatively biased.

Growth rates were calculated for the six major cohorts identified during 1984 sampling. Of interest is the increase in observed growth rate of each subsequent cohort. Growth rates ranged from 0.39 mm/day for the earliest cohort to 0.79 mm/day for the final cohort. Water temperatures increased steadily from abut 8 to 14°C during this time period.

Table 1. Mean number of herring larvae per square-meter surface area near Birch Point, Washington, 1984.

Date	Drayton Harbor (4 stations)	Semiahmoo Bay (12 stations)	Birch Bay (5 stations)
Feb 28	14.3	-	-
March 8	37.9	8.9	-
19	302.3	87.1	0.5
27	199.8	-	-
April 4	12.8	1.1	2.3
15	6.5	1.8	0.8
25	-	5.9	5.2
29	2.3	0.4	0.4
May 1	0.1	-	1.3
9	0.8	6.0	15.9
13	4.7	2.1	3.0
16	-	1.3	0.1
21	-	68.0	1.9
25	-	8.9	7.4
29/30	-	28.6	-
June 2	3.4	4.8	5.1
6	17.1	2.7	7.5
13	0.4	1.3	1.8
17	1.8	4.0	2.6
28	-	0.3	0.3

Table 2. Mean number of herring larvae per square-meter surface area by cohort and date in Drayton Harbor, 1984.

Date	Estimated spawning date					
	Feb 14	Mar 1	Apr 13	Apr 27	May 10	May 20
Feb 28	14.28					
March 8	37.88					
19	12.09	290.25				
27	(5.39)[a]	194.42				
April 4	(0.65)	12.18				
15	(0.26)	(4.87)				
25	-	-	-			
29	0	(0.29)	0.21			
May 1	0	0	0.12			
9	0	0	0.06	0.73		
13	0	0	0	3.58		
16	-	-	-	-	-	-
21	-	-	-	-	-	-
25	-	-	-	-	-	-
29/30	-	-	-	-	-	-
June 2	0	0	0	0	0	3.35
6	0	0	0	0	0	6.64
13	0	0	0	0	0	0
17	0	0	0	0	0	0
28	0	0	0	0	0	0

[a]Numbers in parentheses are probably negatively biased due to decreased larval vulnerability to the gear.

Table 3. Mean number of herring larvae per square-meter surface area by cohort and date in Semiahmoo Bay, 1984.

Date	Estimated spawning date					
	Feb 14	Mar 1	Apr 13	Apr 27	May 10	May 20
Feb 28	-					
March 8	8.92					
19	1.74	85.32				
27	-	-				
April 4	(0)[a]	0.86				
15	(0.03)	(0.47)				
25	0	(0.12)	4.53			
29	0	0	0.33			
May 1	-	-	-			
9	0	0	0.07	5.90		
13	0	0	(0)	2.09		
16	0	0	(0.07)	1.26		
21	0	0	(0)	(1.36)	66.60	
25	0	0	(0.03)	(0.13)	8.81	
29/30	0	0	-	-	-	20.02
June 2	0	0	0	(0.4)	1.15	3.57
6	0	0	0	0	(0.03)	1.73
13	0	0	0	0	(0.10)	(0.16)
17	0	0	0	0	0	(0.05)
28	0	0	0	0	0	0

[a]Numbers in parentheses are probably negatively biased due to decreased larval vulnerability to the gear.

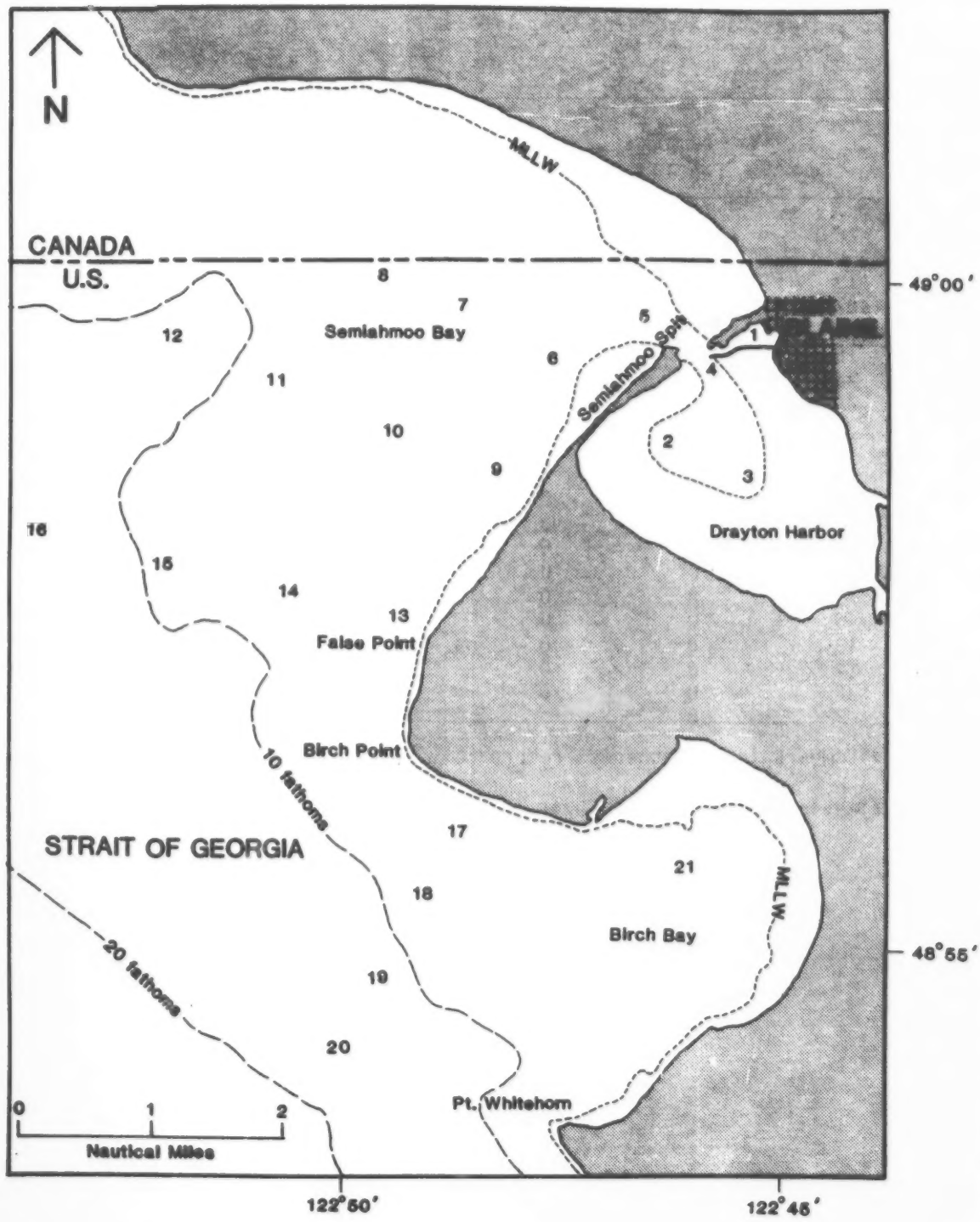

Fig. 1. Study area for 1984 sampling.

SESSION 3

SPECIAL PROBLEMS AND TECHNIQUES

Uptake and depuration of aromatic hydrocarbons by reproductively ripe Pacific herring

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Pacific herring (Clupea harengus pallasi) are an important prey species and a valuable commercial fishery in the north Pacific. The gonads of ripe females are highly valued in foreign markets, and the price per kg of ripe herring is more than for most species of salmon. The inshore spawning strategy of herring stocks makes them vulnerable to oil contamination.

Ripe adult herring were captured by purse seine near Juneau, Alaska and exposed in the laboratory to the water soluble fraction of Cook Inlet crude oil. Exposures were flow-through for up to 10 days followed by placement in clean water for 14 days. Tissues (muscle, liver, ovary, and testis) were collected periodically during and after exposure to oil WSF, and then analyzed for aromatic hydrocarbon content by gas chromatography.

Uptake was rapid into all of the tissues sampled. By 24 hours, the fish exposed to 0.5 ppm WSF had tissue concentrations ranging from 15 ppm in testis to over 50 ppm in muscle. Tissue burdens of aromatic hydrocarbons were primarily dependent on the exposure concentration and not the duration of exposure. For every tissue, exposure to greater concentrations of environmental hydrocarbons resulted in increased tissue loads, but there was little difference between tissue concentrations after 10 days of exposure.

The concentration of aromatic hydrocarbons was different for each of the tissues. Ovary tissue consistently accumulated more hydrocarbons than did testes. Immature ovaries, which are serviced by functional blood vessels, accumulated more hydrocarbons than ripe ovaries. Muscle accumulated unexpectedly high concentrations of aromatics hydrocarbons, particularly when compared to earlier studies from our laboratory with salmonids.

Depuration was rapid except in the gonad tissue. Half of the residues were lost after 48 h in clean water except for gonad tissue which lost half of its residue in 14 days. Spawned eggs lost residues more rapidly than gonad tissue with half of the residue lost after 4 days in clean water.

Inshore exposure of herring prior to spawning will probably contaminate the edible tissues of muscle and ovaries. Gonad tissues valued from commercial fishery purposes would take the longest period after an oil exposure to become uncontaminated.

Induced sexual maturation and spawning of herring by GnRH implants

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INTRODUCTION

Schools of Pacific herring (Clupea harengus pallasi) normally spawn en masse during the spring (Haegele and Schweigert 1985). However, synchrony of sexual maturation and spawning within schools is poorly understood. One factor which may control these reproductive events is gonadotropin-releasing hormone (GnRH). This hormone is thought to trigger the pituitary to release gonadotropin which, in turn, induces gonadal maturation. GnRH-like material is present in the brains of herring as in other teleosts (Sherwood and Carolsfeld in prep.).

To determine the role of GnRH in herring reproduction, we administered superactive GnRH analogues to herring at different stages of sexual development. We then monitored their sexual maturation and spawning to see if development could be advanced. These methods may also lead to a practical protocol for artificial induction of maturation and spawning in impounded herring for commercial use.

MATERIALS AND METHODS

Twelve groups of 20 adult herring (mixed sexes) were used: four groups in September, four in February and four in March. In September and February, the groups were as follows: (1) control untreated, (2) control implanted with blank pellet, (3) experimental implanted with pellet containing 0.02 mg mammalian GnRH analogue, and (4) experimental implanted with pellet containing 0.10 mg mammalian GnRH analogue. One-half of groups 2-4 received a second pellet 2 1/2 weeks later; the other half were sacrificed for determination of gonosomatic index. In March the groups were the same except group 3 received pellets containing 0.10 mg salmon GNRH analogue instead of the low dose mammalian analogue. Second pellets were not implanted in the March groups. All fish were sacrificed at the end of the experiments.

The herring were immobilized by placing them in 4°C water prior to implantation. The pellets were pushed through a stainless steel tube into the peritoneum through a 4 mm incision medial to the pelvic fin. Each group was then placed in a separate 3 m tank of running sea water maintained at 9-11°C. Sexual maturity, as defined by the modified Hjort Index (Hay 1985) was assessed on a weekly basis by gentle squeezing. Gonosomatic index (G.S.I.) of the fish was measured at 2 1/2 weeks after the first or second pellet implantation.

The GnRH analogues were D-Ala^{6}; des Gly^{10} mammalian GnRH ethylamide (Syndel); and D-ALa^{6}, des Gly^{10} salmon GnRH ethylamide (Bachem). Pellets were made of cholesterol/cellulose (4:1, w/w) pressed (Parr pellet press) into cylindrical shapes of 3 x 3 mm. Analogues were mixed with cholesterol/cellulose powder prior to pelletization for groups 3 and 4.

RESULTS

In vitro studies of the pellets using radioimmunoassay showed that most of the GnRH was released into a flow-through saline medium at 9°C by 10 hours (Fig. 1).

The high dose of mammalian GnRH markedly advanced sexual maturity in fish implanted in February and March; 50% of the February fish and 60% of the March fish were spent 5 weeks later (Fig. 2). In contrast, none of the February controls advanced beyond the mature stage (Hjort V) and only 10% of the March implanted controls were spent (Hjort VII). In the March fish, sexual maturation induced by the high dose of mammalian GnRH analogue was distinguishable within one week of treatment (Fig. 3).

Sexual maturation of the February fish was advanced less by the low dose compared with the high dose of mammalian GnRH analogue; 18% of the low dose fish were spent 5 weeks later (Fig. 2). The salmon analogue, administered only as a high dose in March, advanced sexual maturation compared with untreated controls but not with blank implanted controls (Fig. 2). Herring implanted in September remained at an early stage of sexual development (Hjort III); none showed maturation in response to the GnRH analogue treatment (Fig. 2).

The gonosomatic index increased more than 10 fold in all fish between October and March as expected (Hay 1985). Among the groups, however, the index was clearly different only on the final sampling dates in March and April between group 4 and the other 3 groups (Fig. 4). The low gonosomatic index values reflect the high proportion of spent fish in these two groups.

DISCUSSION

An analogue of GnRH is clearly effective in advancing sexual maturation and subsequent spawning in herring. However, the effect of the treatment is controlled by several factors: (1) the sexual maturity of the fish at the time of treatment, (2) the dose of the analogue and (3) the type of analogue. The herring implanted in September were too immature to respond to the treatment which was most effective with the more mature fish. Only after a ten fold or more increase in gonosomatic index did the herring (implanted in February or March) respond to the mammalian GnRH. Even at this time the response was dose dependent. It is possible that a higher dose or a

preparation with slower release of hormone would be more effective in less mature fish.

The two types of analogues tested had identical modifications to their structures, but one was based on the mammalian and the other on the salmon GnRH hormone. At identical doses, the mammalian analogue was clearly effective whereas the salmon analogue was not in the herring. However, in milkfish these two GnRH analogues were equally effective when applied in the same type of pellet used in the present experiment (Marte, Sherwood, Crim, Harvey and Toledo, pers. obser.). Both milkfish and herring appear to have the same forms of GnRH in their brains so that their differing responses to salmon GnRH analogue probably depend on other factors.

It is not yet clear how GnRH affects the maturational process. Two possibilities are (1) GnRH triggers early maturation, which may continue at a normal or accelerated rate thereafter, and (2) GnRH acts on maturation only when the hormone is present in elevated amounts. In this experiment, our evidence supports the first possibility. Our pellets release their hormone within 12 hours in vitro, but the reproductive effects are still evident 3 weeks later. However, we do not know if the maturation rate is accelerated or if the process simply has a "head start". Further support for GnRH as a trigger is that precocious maturation is observed one week after the most effective treatment.

Our findings may have practical significance for the production of sac-roe from impounded herring. GnRH could be used, preferably with a more practical application method, to advance gonadal maturation in fish which have matured to at least stage IV of the Hjort scale.

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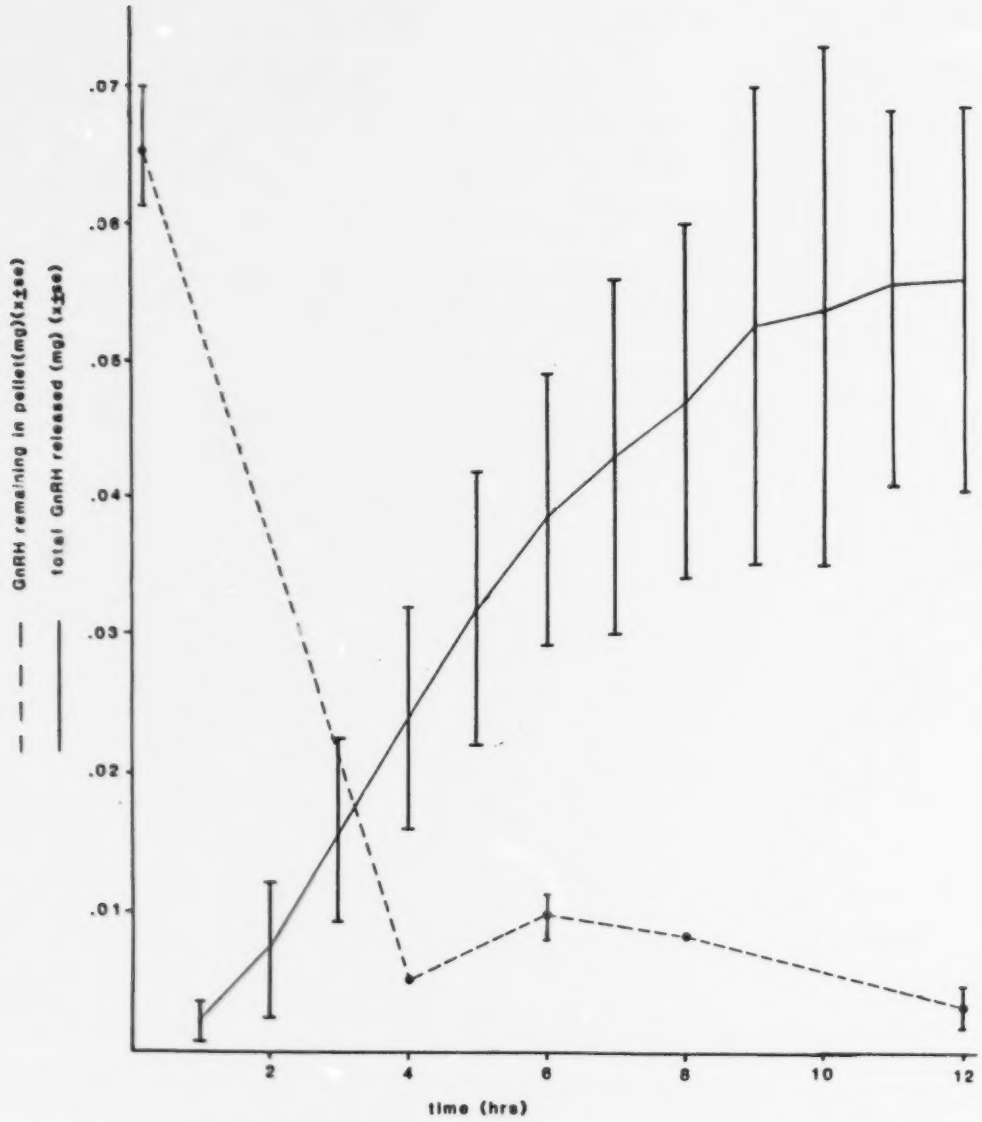

Fig. 1. The total amount of GnRH released from pellets into the surrounding medium is shown by the solid line (mean + SE). The dotted line shows the amount of GnRH remaining in pellets at different times in this in vitro experiment.

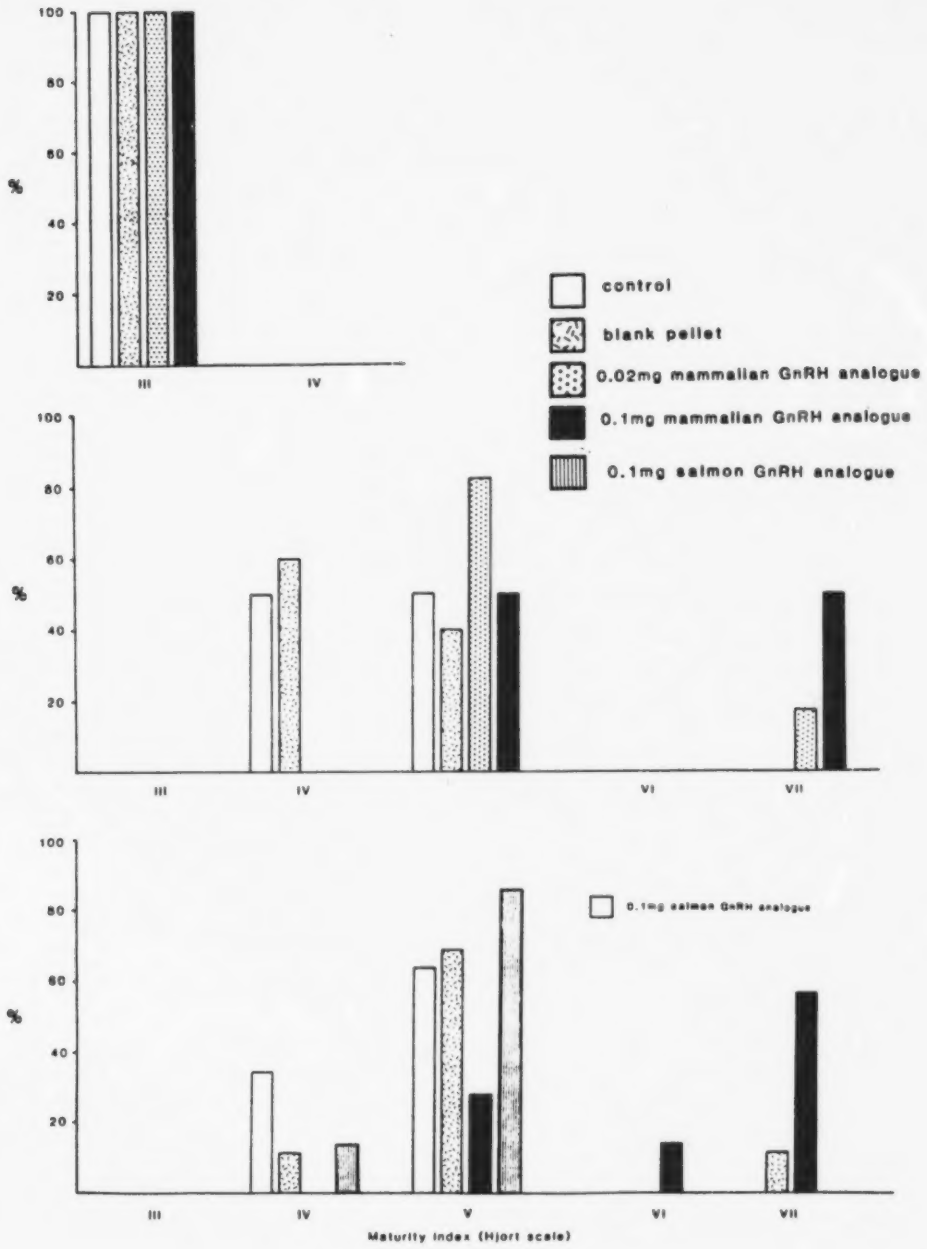

Fig. 2. Effect of GnRH analogue implants on sexual maturation. In the top graph, the fish were implanted with one pellet on 17 September and a second pellet on 1 October. The sampling date was 18 October. In the middle graph, the pellet implants were on 22 February and 14 March; the sampling date was 30 March. In the bottom graph, the implants were on 14 March and the sampling date was 9 April. The Hjort scale refers to the following stages: developing (III), maturing (IV), mature (V), ripe (VI) and spent (VII).

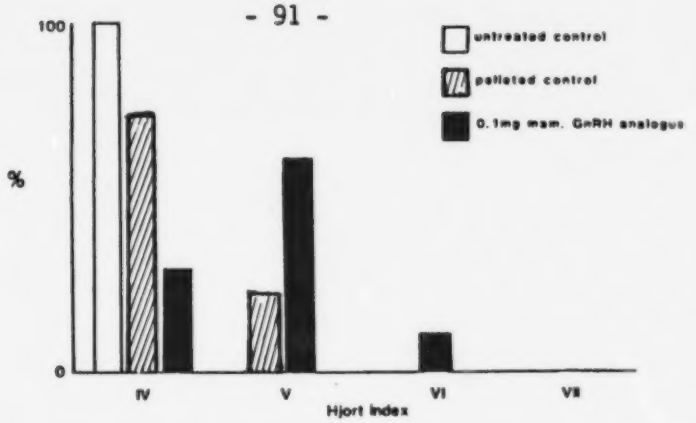

Fig. 3. The effect of a single GnRH analoque pellet on sexual maturation at one week after treatment.

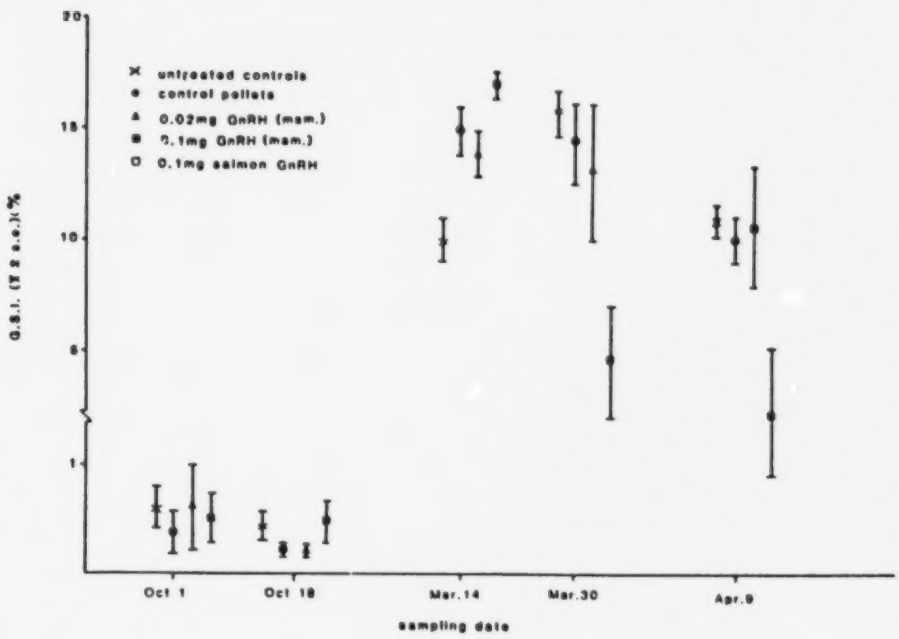

Fig. 4. The gonosomatic index (G.S.I.) for groups of herring at different sampling dates. GnRH (mam.) refers to mammalian GnRH analogue and salmon GnRH also refers to an analogue; both are the D-Ala^{6}, des Gly^{10} GnRH ethylamine forms. Four groups of fish were either untreated or implanted with single pellets on 17 September; one-half were sampled on 1 October; the other half were given a second pellet on 1 October and sampled on 18 October. The second set of 4 groups were untreated or given a single pellet on 22 February; one-half were sampled on 14 March; the other half were given a second pellet on 14 March and sampled on 30 March. The final set of 4 groups were untreated or given a single pellet on 14 March and sampled on 9 April. The symbols represent the mean $\pm$ SE.

Observed recovery rates for anchor tags in B.C. herring fisheries

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Herring have been tagged in British Columbia with external anchor tags at some level since 1979. However, major taggings were only conducted from 1980 to 1983. Herring were tagged either in the fall, prior to inshore migration or in inshore holding areas, or in the spring, prior to spawning. The recoveries in subsequent years were analysed to determine the level of actual recovery.

Reported recoveries were adjusted for observed reporting of tags in the catch (0.4), and further adjusted for simulated gillnet gear selectivity for fish tagged in the fall (0.8 in the first year). A tag density ratio (tags per t in catch/tags per t in stock at release) was calculated, and the log of this ratio was regressed against days at large. Equations had an r-squared of 87.3% for fall taggings and 72.2% for spring taggings. Recoveries over time were higher for fall ($TDR = 0.395 \cdot DAL^{-0.00324}$) than for spring ($TDR = 0.136 \cdot DAL^{-0.00294}$) taggings. (TDR = tag density ratio, DAL = days at large.) Recoveries that can be expected in B.C. herring fisheries using tags and techniques currently in use are given in Table 1.

Low recoveries may be due to a number of reasons. Low recoveries in fisheries immediately after tagging are probably the result of stress and injury induced mortality from handling and from tag shedding. Handling mortality appears substantially higher for herring tagged prior to spawning than for herring tagged in the fall, probably because the fish are hardier in the fall. Handling mortality and tag shedding most likely continues, but at a much lower level, while the fish is at large. The tag density may also decrease as a result of higher predation on tagged fish and the tag density is substantially diluted by recruitment to the stock of first time spawners.

Table 1. Expected tags in the catch for a stock of 30,000 t that is tagged at a density of 0.5 tags/t (15,000 tags) and harvested at 20% with 1000 t allocated to a fall food fishery and 5000 t allocated to a spring roe fishery.

Tagging	Stock (t)	Tags	Tags/t	Fishery	Catch (t)	Av. days at large	Tags in catch
Fall	30000	15000	0.5	Immediate	1000	1	198
				1st roe	5000	100	469
				1st food	1000	365	13
				2nd roe	5000	465	31
				2nd food	1000	730	1
Spring	30000	15000	0.5	Immediate	5000	1	340
				1st food	1000	240	13
				1st roe	5000	365	29
				2nd food	1000	605	1
				2nd roe	5000	730	2

Hydroacoustic "stepping-down" technique to estimate herring density

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This method allows field staff to estimate herring density inshore without the expense and sophistication of scientific hydroacoustic equipment. The echo sounder is an off the shelf commercial sounder modified with click stop gain control with 3 db intervals between each gain step. The idea is that the echo sounder is calibrated for sounding at gain step 7 and when a herring school is encountered, the gain is stepped down until the tracing on the echogram appears. In this way you end up with a consistent and standardized method of judging the actual density; one step up from judging the density by the colour of the echogram tracing. I should mention that this method of conducting herring surveys by echo sounding and the resulting biomass estimate is an art and not a science. The "Standard Technique" using the school dimensions and density and the subsequent conversion table was used as the basis for the "Stepping Down" conversion table and was developed over the years with input from Lloyd Webb and Dennis Chalmers. The "Stepping Down" technique certainly was not developed to take the place of a sophisticated Echo Integration system but was developed to come up with a relative abundance using "off the shelf" echo sounding equipment.

On the B. C. coast 30-40 vessels conduct herring surveys at one time and it is not possible to provide other than "off the shelf" echo sounding equipment and in order to provide relative abundance estimates a standardized technique for interpreting density is necessary. For today's presentation, I am assuming the herring are inshore, are adults and, because the biomass estimates are made during the hours of darkness, the herring are no deeper than 55 m. Also, because the survey is during the hours of darkness, the herring will be a layered, or skimmered, schooling formation. A skimmer is the terminology used for a herring school in a layered distribution during the hours of darkness. A skimmer is normally distributed over a fairly large area, i.e. a 9 m light density skimmer school of 3.4 km^2 represents 2722 t of herring. The skimmer schooling formation is the most ideal schooling formation for estimating herring biomass.

INFORMATION REQUIRED TO PRODUCE A RELATIVE HYDROACOUSTIC BIOMASS ESTIMATE

Dimensions

- Horizontal - by Radar or Loran C photo
- Vertical - by echo sounder

Density

- by echo sounder. Of the two requirements, density is the most troublesome in terms of consistency. For example, a change in interpreting the density of

the echogram by 3 db can result in under or over estimating the biomass by 100%.

EQUIPMENT

Sounding Platform - The platform can be relatively small if the survey area is in protected waters (a 6 m vessel would suffice).

Echo Sounder - It is mandatory to know the receiver strength between gain steps; each 3 db step represents one density (off the shelf model - TVG desirable).

Radar - Radar is necessary because the work is carried out during the hours of darkness and is used for plotting the horizontal dimensions of the school.

Personnel - Three people are desirable; one to steer the vessel; one to interpret the vertical depth and density as well as to provide the radar plotting information; and one to plot the information on a marine chart.

SUMMARY OF METHOD

1. A zig-zag search pattern is used and when a herring school is encountered the ship's position is determined by a radar fix and then the vertical depth and density recorded on a marine chart. The ship's position is updated whenever the vertical depth or density changes (Fig. 1).

2. The size of the school, average vertical depth and density is used to calculate the biomass using a reference table as a guide (Fig. 2). Table 1 is the reference table for the "Standard Technique" or tried and true method and works if the echo sounder is set-up the same way each time and if the density from the colour of the herring school on the echo is interpreted in a consistent manner. The problem with this method is I would look at the echogram and say to myself, "Did I call that light or medium density last year?" Depending on which direction I went, I could under or over estimate the biomass estimate by 100%.

The new "Stepping Down" method allows you to use the echo sounder to interpret the density for you, thus removing some of the subjective interpretation. There is still some interpretation because there always seems to be a slight tracing on the echogram, thus you have to decide whether to step the gain down one more time or leave it at that. I suggest you accept a small bit of tracing. Anyone with experience in echo sounding herring knows that a school of herring of apparent uniform density can vary tremendously and that is where the art of estimating herring stocks replaces science when using "off the shelf" equipment. Table 2 is the reference table developed for the

Stepping Down Technique using the reference table for the "Standard Technique" as a data base. As I said before, there is still some interpretation involved because there always seems to be slight trace on the echogram, probably due to the density variation and you have to decide whether to step down one more gain step or leave it at that. We find, after practice, we can Step Down very quickly and have found the technique almost as fast as estimating the density by judging the colour of the herring school on the echogram. We have used this method successfully for four years with good results so are gaining confidence in the method. Every year we think to ourselves perhaps this is the year it won't work, but also feel if we maintain consistency in our methods it will work (Figs. 3 & 4).

Before I finish, I would like to say the main thing to remember when estimating herring stocks is to be consistent:

- Your sounder has to be tuned exactly the same way each time, i.e. gain, power, etc.
- Your vessel speed to be the same.
- Try to calculate the school dimensions as accurately as possible.
- Try to be as consistent as possible in determining the density.

If you are consistent from one survey to the next you should be able to come up with a relative abundance estimate. A calibrated echo integration system is the most accurate but a relative abundance can be obtained with an off the shelf echo sounder.

As a final comment in regard to having sufficient echo sounding equipment - you can have a million dollars worth of hydroacoustic equipment and unless you know where and when to sound you may not find a herring. Remember to look out the wheelhouse window for birds, sea lions, etc. and use common sense.

Table 1. Tons of herring per square nautical mile as estimated by echo sounding surveys.

Light Intensity Simmers		Light to Medium Skimmers		Medium Intensity Skimmers	
1 fathoms deep	600 tons	1 fathoms deep	900 tons	1 fathoms deep	1,200 tons
2 " "	1,200	2 " "	1,800	2 " "	2,400
3 " "	1,800	3 " "	2,700	3 " "	3,600
4 " "	2,400	4 " "	3,600	4 " "	4,800
5 " "	3,000	5 " "	4,500	5 " "	6,000
6 " "	3,600	6 " "	5,400	6 " "	7,200
7 " "	4,200	7 " "	6,300	7 " "	8,400
8 " "	4,800	8 " "	7,200	8 " "	9,600
9 " "	5,400	9 " "	8,100	9 " "	10,800
10 " "	6,000	10 " "	9,000	10 " "	12,000
11 " "	6,600	11 " "	9,900	11 " "	13,200
12 " "	7,200	12 " "	10,800	12 " "	14,400
13 " "	7,800	13 " "	11,700	13 " "	15,600
14 " "	8,400	14 " "	12,600	14 " "	16,800
15 " "	9,000	15 " "	13,500	15 " "	18,000
16 " "	9,600	16 " "	14,400	16 " "	19,200
17 " "	10,200	17 " "	15,300	17 " "	20,400
18 " "	10,800	18 " "	16,200	18 " "	21,600
19 " "	11,400	19 " "	17,100	19 " "	22,800
20 " "	12,000	20 " "	18,000	20 " "	24,000
21 " "	12,600	21 " "	18,900	21 " "	25,200
22 " "	13,200	22 " "	19,800	22 " "	26,400
23 " "	13,800	23 " "	20,700	23 " "	27,600
24 " "	14,400	24 " "	21,600	24 " "	28,800
25 " "	15,000	25 " "	22,500	25 " "	30,000

NOTE: The above figures are Estimates only and past data indicates that they tend to be conservative. The data may be plus or minus up to 10%.

Table 2. Shows the estimated biomass of each step at a standard of one fathom of herring/square mile from the standard gain setting of 7.

Number of Gain Steps down	Gain setting	Density	Biomass (Tons) (of one Fm. depth of herring in one square mile)
0	7	v.v. light	150
1	6	v. light	300
2	5	light	600
3	4	medium	1,200
4	3	heavy-1	2,400
5	2	heavy-2	4,800
6	1	heavy-3	9,600

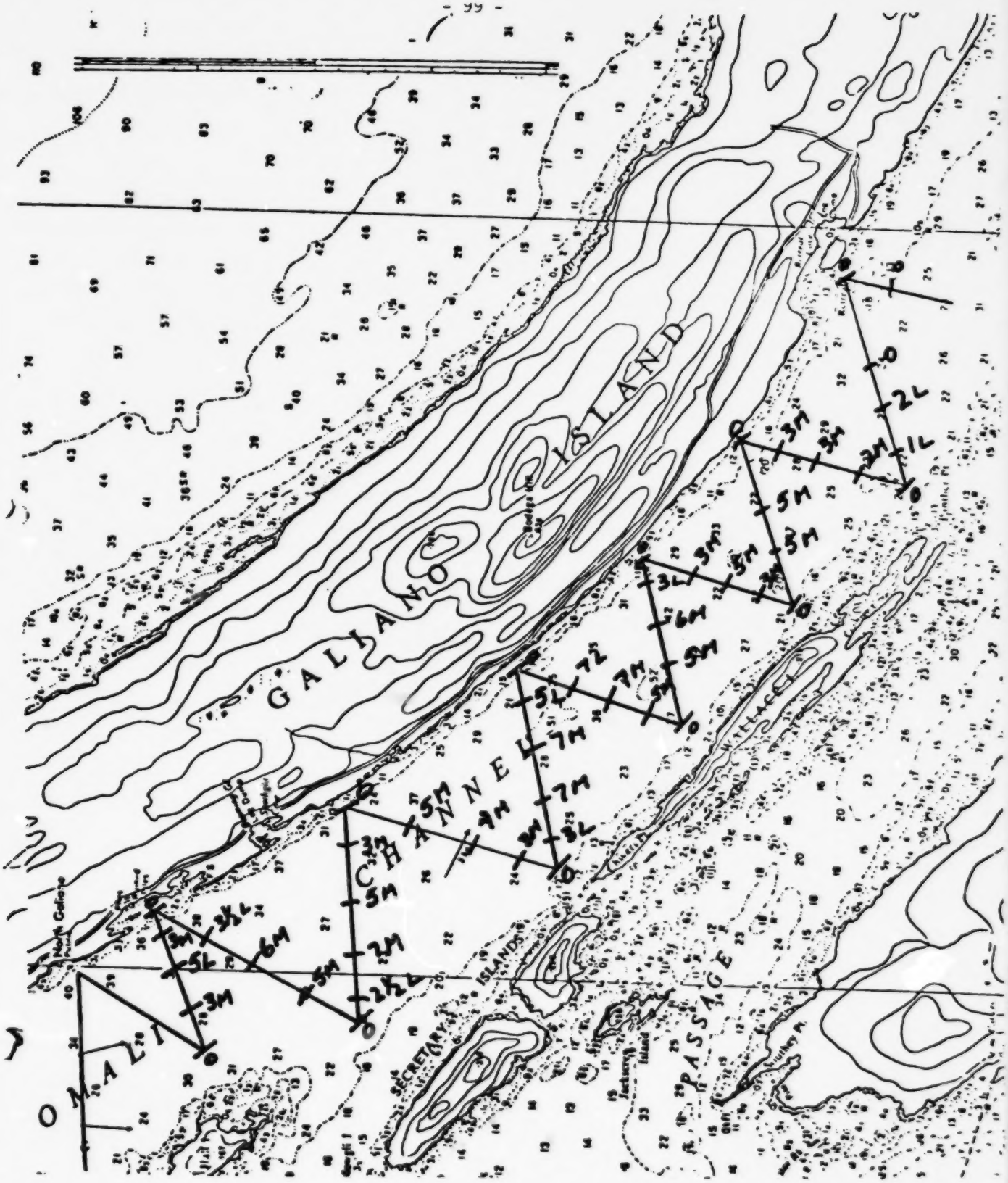

Fig. 1. Depth and density of a herring school plotted on a marine chart.

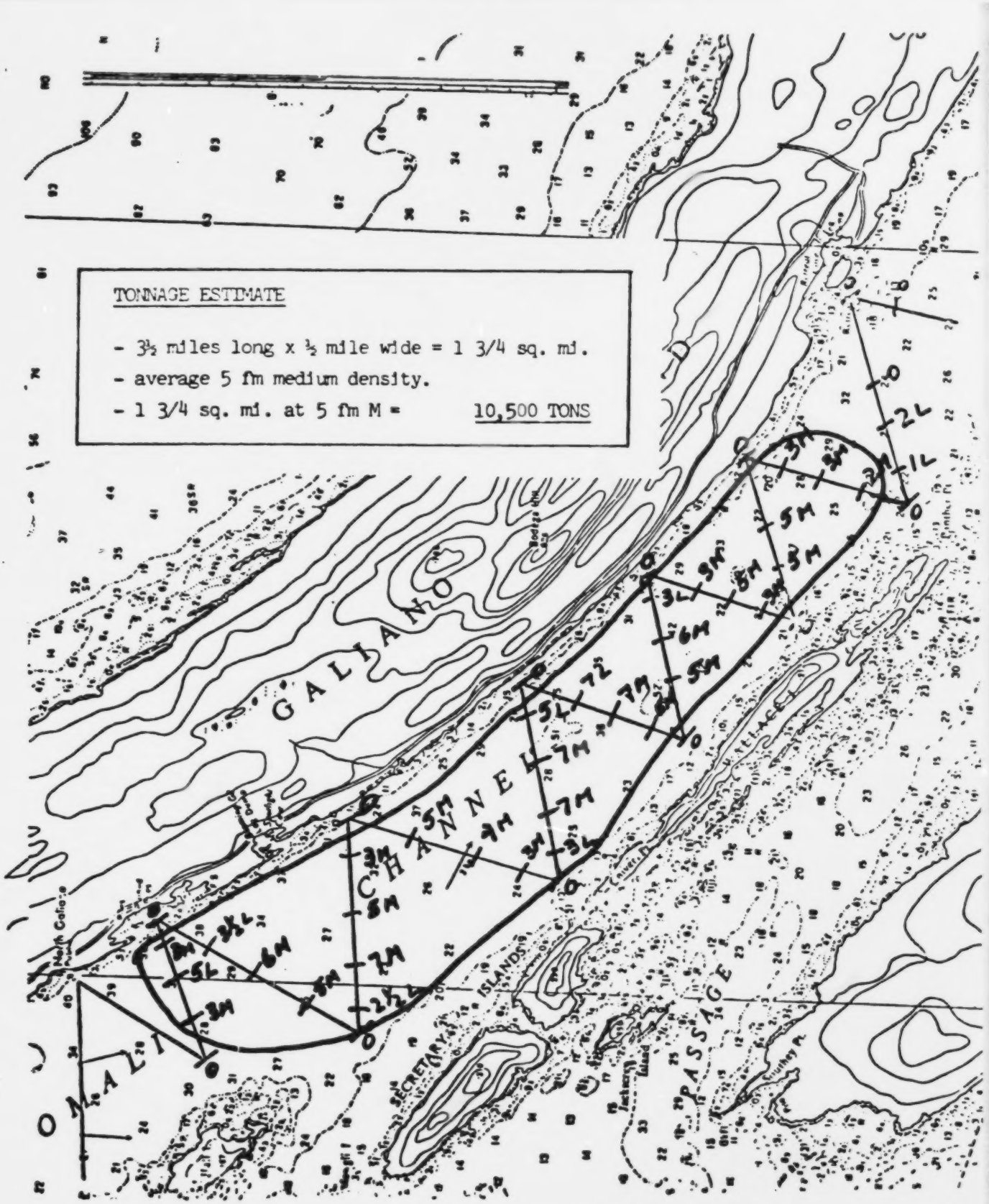
TONNAGE ESTIMATE
- 3½ miles long x ½ mile wide = 1 3/4 sq. mi.
- average 5 fm medium density.
- 1 3/4 sq. mi. at 5 fm M = 10,500 TONS
GALIANO
CHANNEL
SECRETARY ISLANDS
PASSAGE
OMALL

Fig. 2. Depth and Density of a herring school plotted on a marine chart with the school boundaries and biomass estimate.

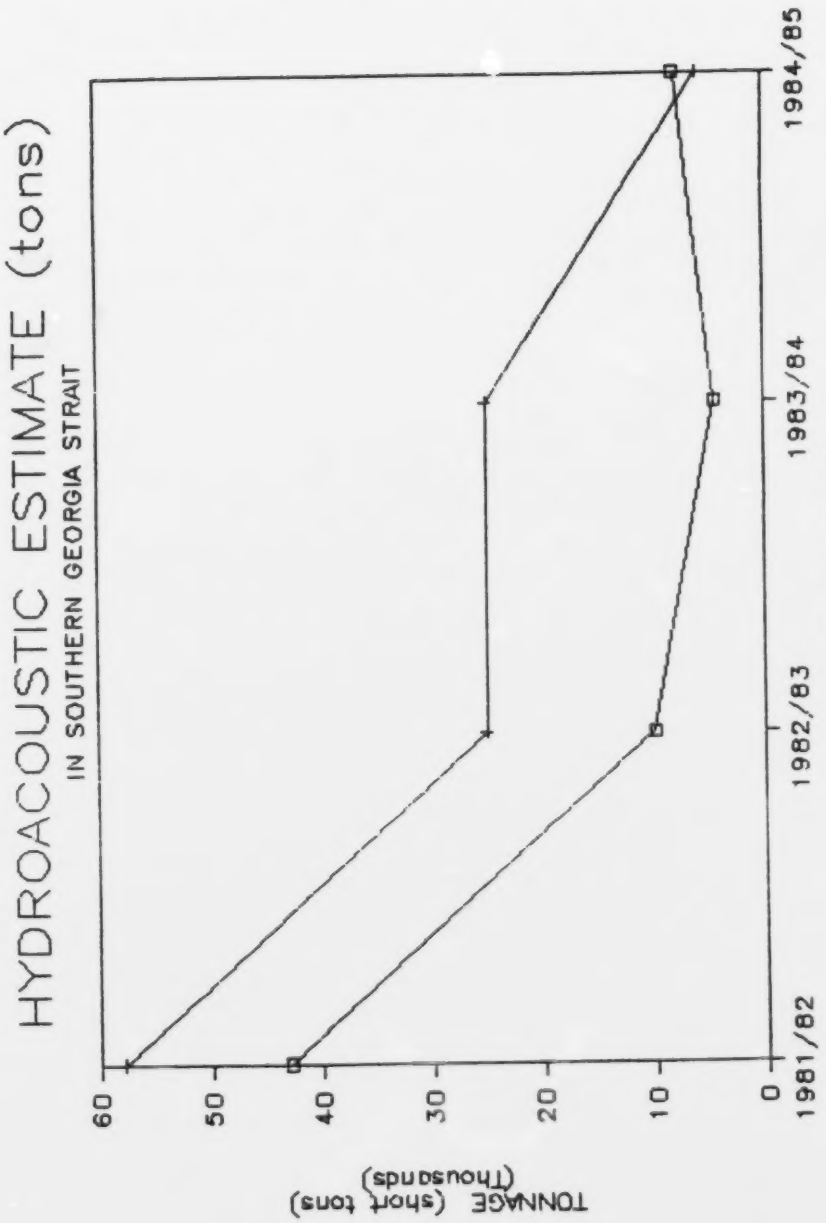

Fig. 3. Hydroacoustic estimate for the southern Strait of Georgia.

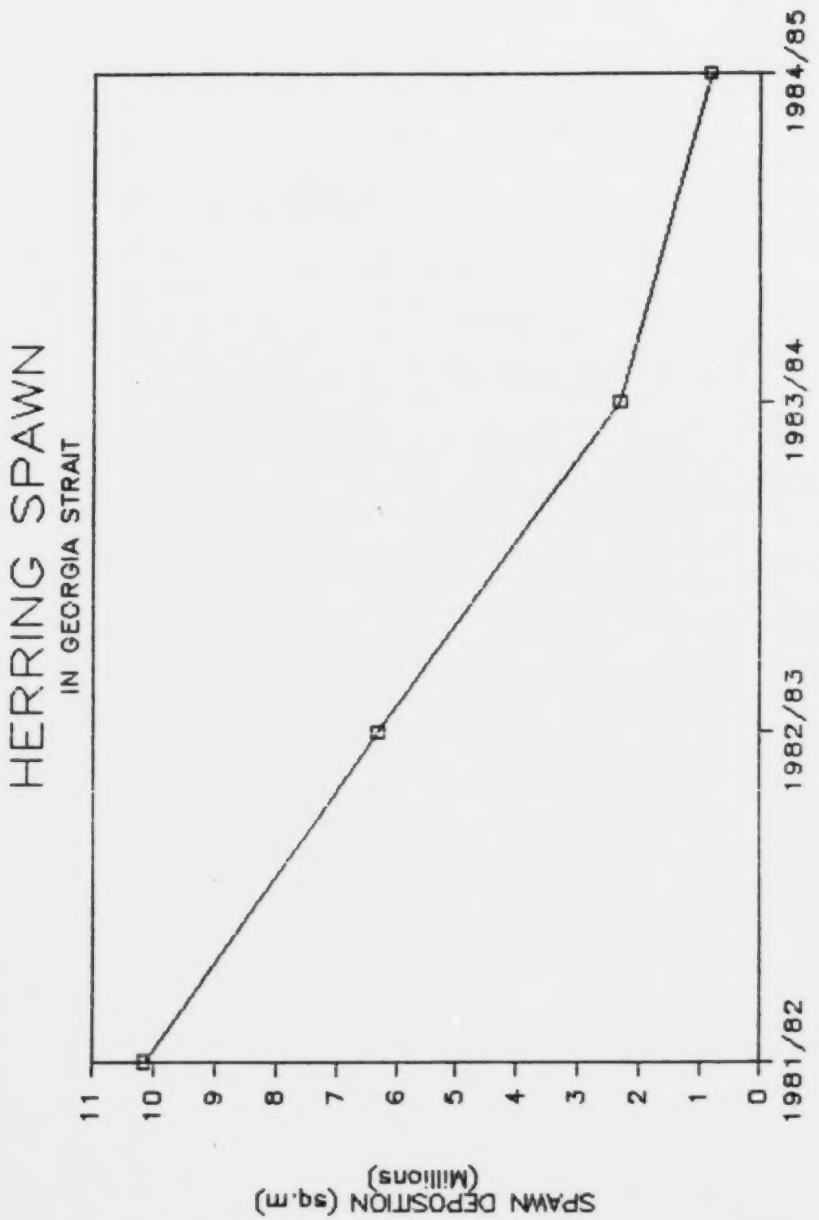

Fig. 4. Snawn denosition in the Strait of Georgia.

SESSION 4

RECRUITMENT

The influence of inter-annual variations in winter sea temperatures on the fecundity and egg size of Pacific herring (*Clupea harengus pallasi*)

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The fecundity of Pacific herring was unusually high in 1983, when the coastal waters of British Columbia were abnormally warm because of the strong El Niño Southern Oscillation event. Data for 2937 fish, collected from seven locations over five years, were used to evaluate the effect of winter sea temperature and stock biomass on size-specific ovary weight and fecundity at spawning. Ovary weight remained constant over years and among locations. Fecundity was significantly higher in 1983 and did not differ between locations within years. Results of multiple regression analysis indicated that mean sea temperature between 60 and 90 days before spawning best accounted for variations in fecundity. We suspect that temperature influences fecundity by regulating gonadotropin concentrations to control the rate of pre-ovulatory atresia. We suggest that the inter-annual variations in egg size occur as a consequence of the changes in fecundity. These variations in fecundity and egg size seem to be adaptive; they would compensate for the increase in predation pressure and reduction in food particle size occurring at higher temperatures by producing more eggs and larvae, and reducing larval size to preserve the ratio between larval and food particle size.

Influence of climatic variability on herring in the eastern Bering Sea

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The eastern Bering Sea contains two major groups of herring; a northern group spawning in coastal areas between Kuskokwin Bay and Norton Sound, and a southern group spawning in Bristol Bay and bays north of Cape Newenham (Fig. 1). These herring migrate long distances between winter grounds located near the continental shelf edge and coastal spawning grounds. Other smaller local groups, which are believed to be nonmigratory, occur in the Aleutian Islands area, in the Bering Straits and in Chuckchi Sea. The two major spawning groups of herring are distinguished by growth characteristics with stocks in the northern group exhibiting significantly lower length-at-age than herring in the southern group (Fig. 2).

These growth differences appear due to the productivity of the areas covered during the summer-autumn feeding migration (Fig. 1). The difference in the productivity between the northern shelf and the southern shelf relates to water temperatures and the extent of winter ice cover (Fig. 1). In warm years the winter ice pack covers only the northern shelf and in cold years can cover most of the eastern Bering Sea shelf. The annual climatological differences in ice cover is expressed in herring growth rates with lower than average growth in cold years and the converse in warm years (Fig. 3). The response of growth to climate is believed a result of changes in the production of invertebrate prey or modification of the summer migration routes.

The climate induced variation in growth may influence the spawning stock size. Recruitment to the spawning population appears to be related to size; therefore, in anomalous years, the spawning population may differ from expected numbers. The quantity of eggs produced appears to be a function of size or weight of an individual and may also vary with environmentally induced variations in growth. Work is underway to examine the magnitude of these variations and their influence on model estimates of recruitment.

Herring in the eastern Bering Sea have exhibited a wide variation in recruitment (Fig. 4a). This recruitment correlates poorly with adult biomass (Fig. 4b) and leads one to hypothesize environmental variability as a factor influencing year-class strength. El Niño events have been hypothesized as producing strong year-classes but for eastern Bering Sea stocks this relationship is tenuous. Comparison of year-class size with the southern oscillation index indicated that the two largest year-classes (1957, 1958) in the eastern Bering Sea were associated with anomalously warm years but other year-classes were randomly distributed among cold, normal and average years independent of stock size. Examination of monthly averages of climatic parameters from weather stations located adjacent to major spawning grounds revealed an extremely poor correlation with year-class strength for May and June, the larval period, a time when effects would be expected. The only mean

values which appear to correlate with year-class strength is wind direction and magnitude. The prevailing wind during the early life history of herring results in onshore transport and larval retention. Wind data suggest that weak year-classes may result in years when the storm track shifts and offshore transport predominates and the larvae are dispersed to unfavorable offshore areas. Direct coupling with wind events in the eastern Bering Sea is plausible as the coastal shelf is quite shallow with the 10 m contour several kilometers offshore. The relationship with wind is not strongly correlated which suggest that single events such as intense gales may be the causative agent. Another moderating variable which must be considered is tides. Tidal currents are the principal currents in the Bering Sea and may modify wind driven transport.

CONCLUSIONS

Eastern Bering Sea herring move from wintering areas on the outer continental shelf to the broad shallow inner continental shelf for spawning and feeding. The temperature regime and biological production of the inner shelf is largely affected by the severity of annual climatic events. This is largely due to winter conditions and the extent of the ice pack; however, recent studies have shown that intense summer storms can completely mix the water column and influence productivity. These climatic events appear to produce inter-annual variations in growth which may also influence age-specific maturation rates and absolute fecundity.

Recruitment and spawning population data for the eastern Bering Sea do not appear to fit expected spawner-recruit relationships. The large departure from the expected models is assumed due to climatic variation. Initial investigations of average annual and monthly values of climatic indices during the spawning and larval periods do not produce any significant correlations with recruitment. Seasonally averaged wind vectors produced the highest correlations, suggesting that in years of water mass retention in coastal waters there is better recruitment.

Future investigations will be directed toward examining the relationship of water mass transport to year-class strength by examining net water mass transport from spawning grounds, computed from wind and tide data.

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Rogers, D. E., K. N. Schnepf, and P. R. Russell. 1984. Feasibility of using scale analysis methods to identify Bering Sea herring stocks. Fish. Res. Inst., Univ. Wash. No. 8402, 48 p. Seattle, WA.

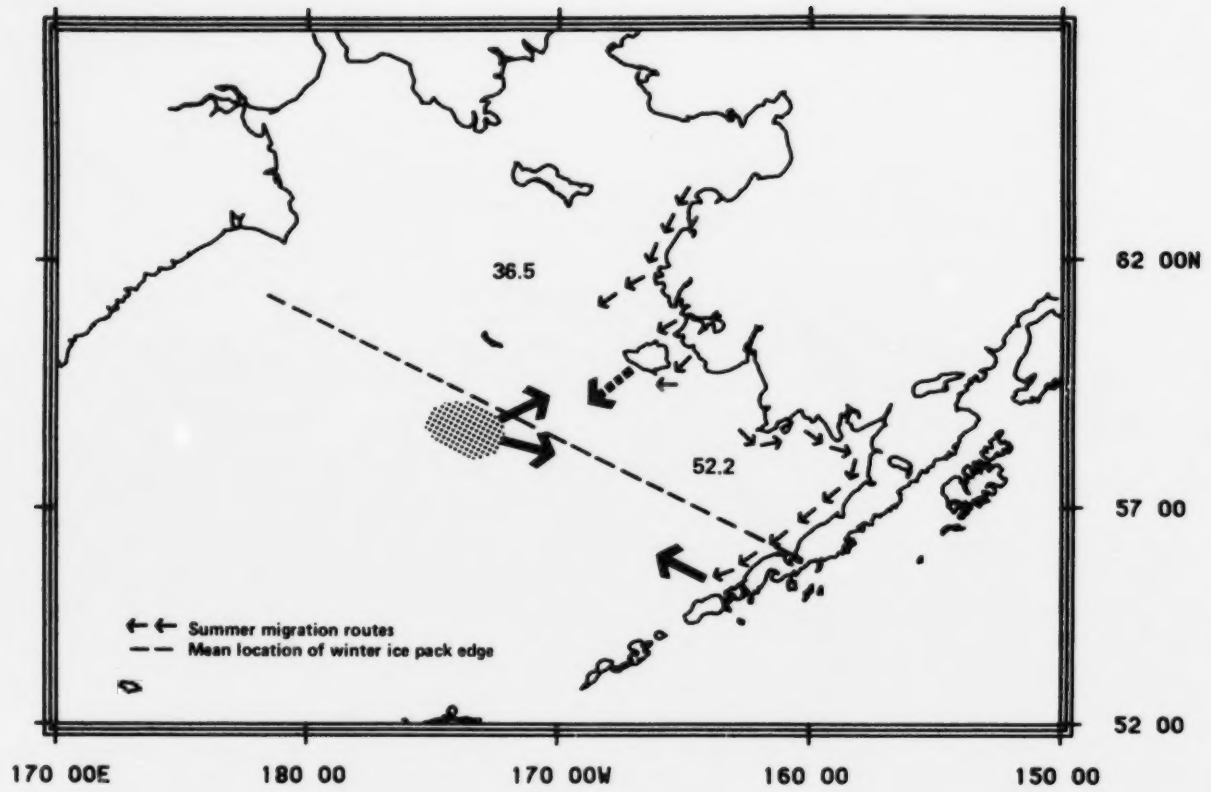


Fig. 1. Location of Bering Sea herring winter grounds and migration routes of the northern and southern spawning groups to and from coastal spawning grounds. Also shown is the average location of the edge of the winter ice pack (dashed line) and the mean standing stock of net plankton (g/m2 wet weight) in each migration corridor. Plankton data from Motada and Minoda (1974).

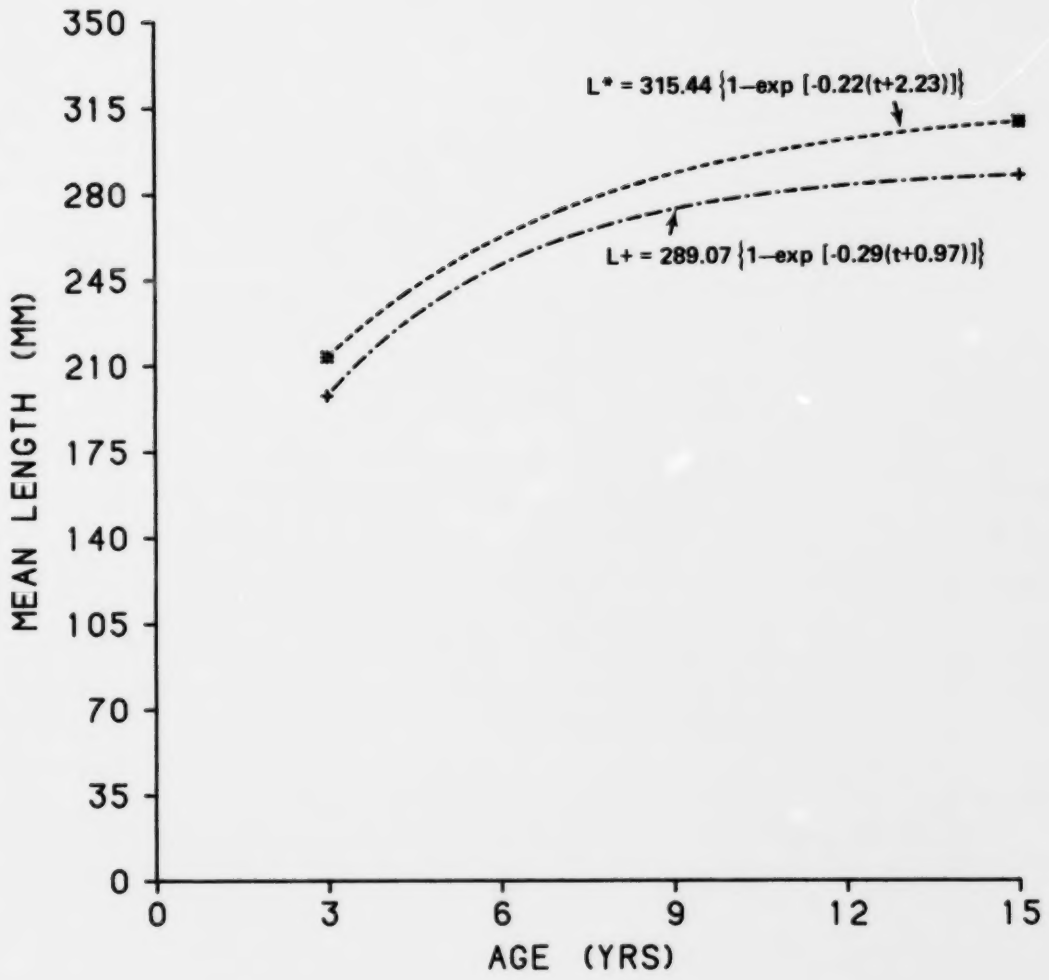


Fig. 2. Growth curves for the two herring spawning groups in the eastern Bering Sea. Southern group (L*), Northern group (L+).

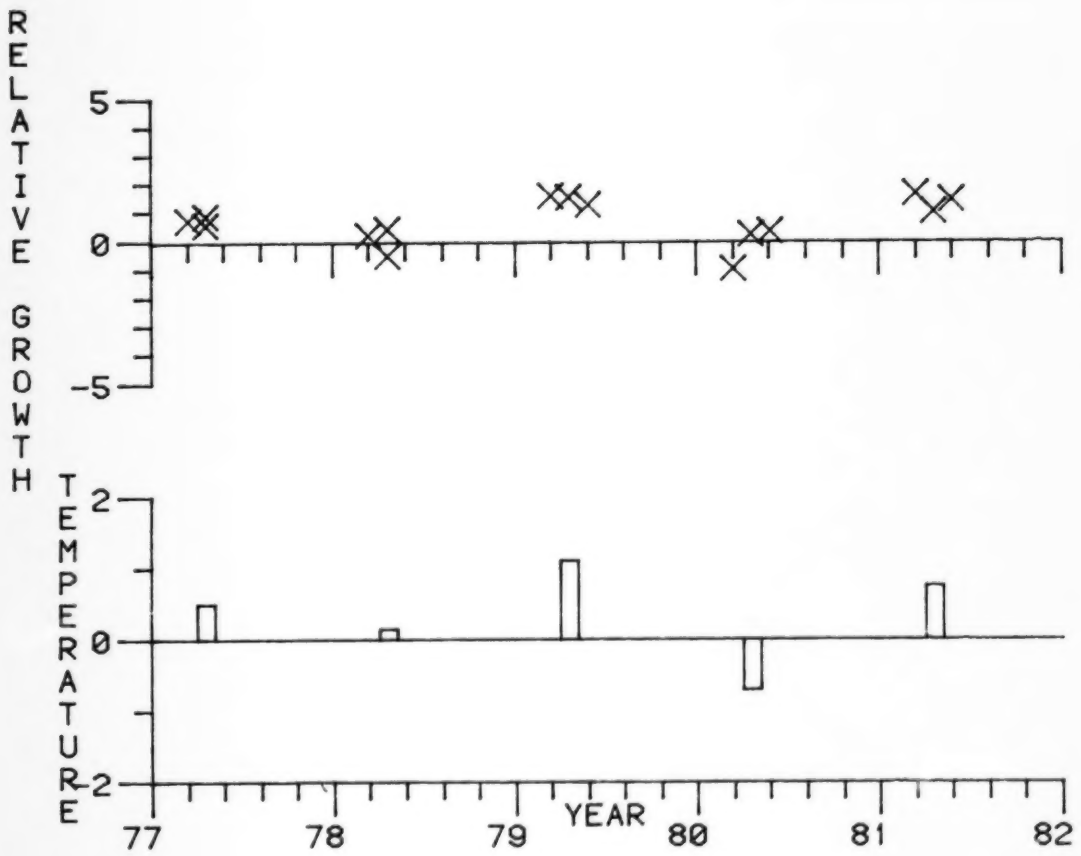
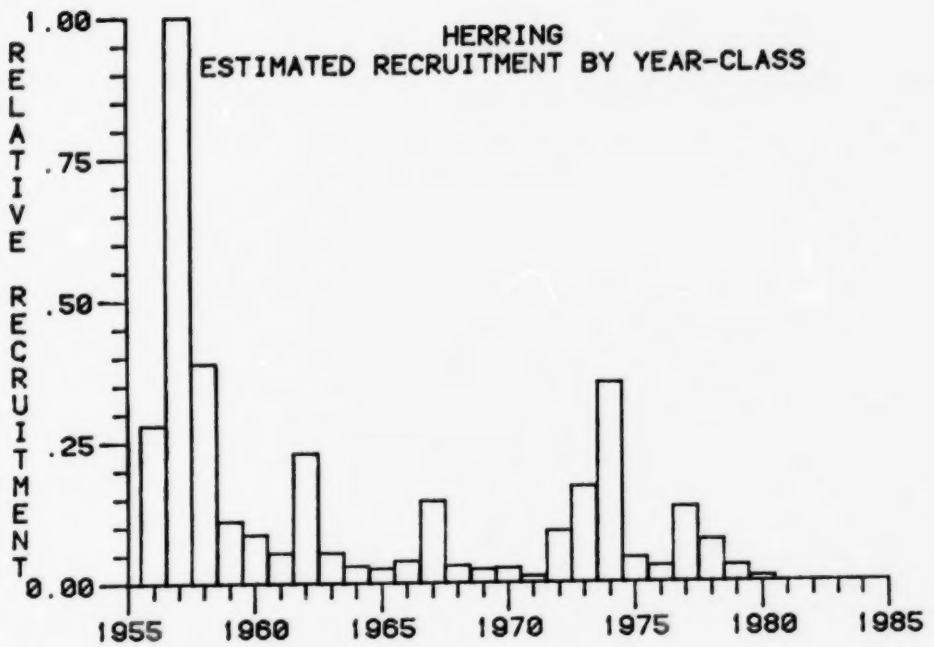


Fig. 3. Relative growth of herring spawning in northern Bristol Bay (number of standard deviations from the mean distance between annuli for each age group) and the means of the monthly air temperature deviations (May-August) for Bristol Bay. Data from Rogers et al. (1984).



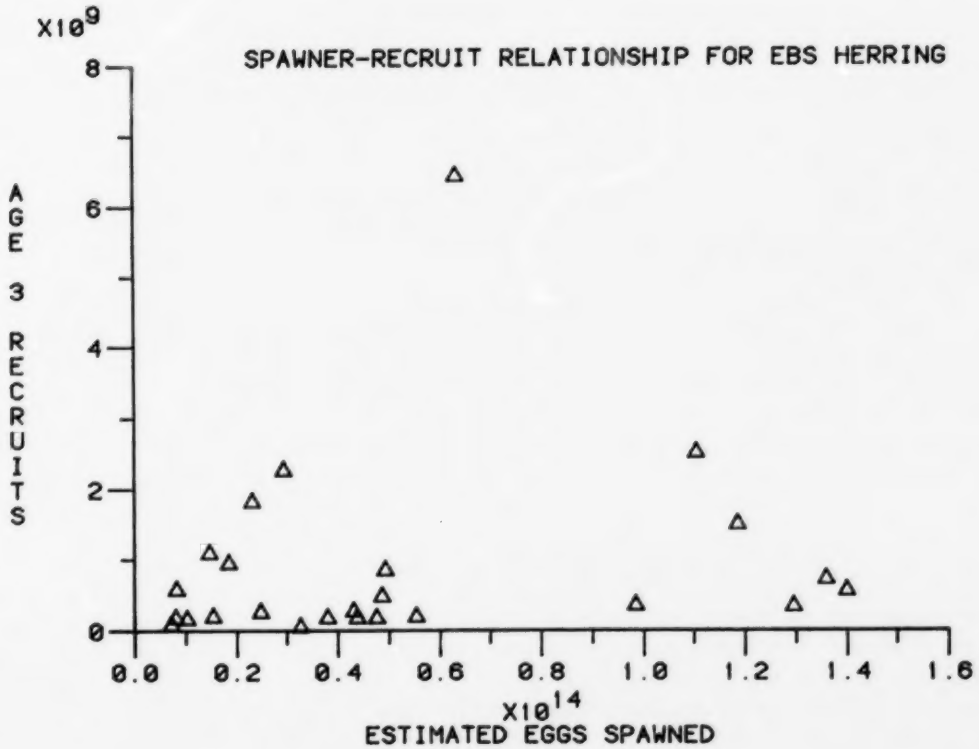


Fig. 4. a) Relative recruitment of herring in the eastern Bering Sea by year-class, 1956-1980. b) Spawner-recruit relationship for eastern Bering Sea herring in terms of age 3 recruits per spawners in estimated number of eggs released.

Recent changes affecting Washington State's Strait of Georgia herring stocks

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An analysis was conducted of data pertaining to Washington State's Strait of Georgia herring stock. The time series includes biological data collected since 1976, and abundance and catch at age estimates compiled by Washington State Department of Fisheries since 1983.

The biomass of the herring stock has declined steadily from about 13,150 t in 1973 to less than 5440 t presently (Fig. 1). The decline has continued despite the fact that there has been no fishing since 1980, except for a minor catch of 450 t in 1982. During this period of decline a number of important biological parameters have changed, and 1980 seems to have been an important year of transition.

The frequency of two-year-olds in the spawning stock increased sharply in 1980, and although variable, has remained higher than in previous years (Fig. 2). The variability is exacerbated by relative year class strength, but this result clearly suggests that there has been a decrease in the age of maturity.

Juvenile growth rate, as reflected by average length of two-year-olds in the catch, has also increased, reaching a peak in 1980 (Fig. 3). The low value in 1984 is probably the result of the 1982-83 El Niño. The seasonal growth and energy storage of the fish sampled in the early spring of 1984 occurred during the spring and summer of 1983, a time when the full effects of El Niño were most apparent. The growth rates of older fish in the 1984 catch were also affected. The observed linear growth increments of the 4-, 5-, and 6-year-olds were the lowest on record in 1984, and that of the 3-year-olds the second lowest ever observed.

Physical condition of spent fish (somatic body weight of a 200-mm fish) declined sharply in 1980 and has remained low ever since (Fig. 4). While physical condition declined, relative reproductive effort increased (Fig. 5). The average gonad somatic index (GSI = gonad weight/somatic body weight of a 200-mm fish) during the period 1976-79 was 0.25. The average GSI since 1980 was 0.30, representing an increase in relative reproductive effort of 20%.

There also apparently has been a substantial increase in the cohort-specific natural mortality rate (Fig. 6; points not connected by lines were excluded from the analysis because of problems with the data, although their exclusion does not affect the overall conclusion). The average of the 1981-1973 estimates was 0.37, which is similar to that estimated by Schweigert and Hourston (1980) for Barkley Sound herring (0.36). The average M value for 1984-1979 was 0.56. These averages are not meant to imply that mortality has gone from one stable value to another, but it is evident that the natural mortality rate has increased substantially in recent years.

A consideration of the sequence of events suggests some partial explanations for the changes which have affected the herring stock. The initial decline in biomass preceded the increase in mortality rate, which in turn preceded the 1980 transition in the reproductive effort and condition indicators. Fishing pressure probably contributed to the initial decline in biomass, particularly in 1974 and 1975 when exploitation rates were high. The increase in natural mortality first affected the 1974 cohort but could not have influenced the decline in biomass until at least 1977 when the three-year-olds entered the fishery. From 1977 through 1980, both fishing and higher natural mortality contributed to the stock reduction. Despite the closure of the fishery, there have been no signs of recovery and a contributing factor must be the absence of any strong year classes since 1978.

The timing of changes in biological parameters suggests both density dependent and possibly genetic effects. An increasing juvenile growth rate and a decreasing age of maturity are generally interpreted as density dependent responses to declining biomass. The growth rate data in particular conform well with this supposition. However, there also may have been a genetic component to the apparent transition in the life history. The reproductive effort and condition indicators changed abruptly in 1980 and therefore followed the increase in mortality rate. It is worth noting that the two-year-olds in 1980, which dominated the stock in that year (more than 50% in terms of frequency), were the first progeny of adults that had been subjected to the selection pressure of higher natural mortality.

In analyzing these between-year differences in biological parameters, it is important to note that there is no single indicator that by itself convincingly demonstrates that the stock has been seriously affected. However, all of the parameters taken together are consistent in suggesting that Washington's Strait of Georgia herring stock has undergone a major transition in its life history.

Finally, there are at least two feedback mechanisms which may tend to inhibit stock redevelopment and the return to previous conditions (Fig. 7). The combined events of declining biomass and increased natural mortality have led to higher juvenile growth rates, earlier recruitment, higher relative reproductive effort, and thus reduced physical condition, which, in itself, is a contributing factor to the increase in natural mortality. The combined events have also led to reduced population fecundity and a compressed age structure (fewer old fish). Because older fish tend to spawn larger eggs earlier in the season, the population now samples less of the time/space continuum. As a result, it is less likely that the strong year classes needed to rebuild the stock will occur.

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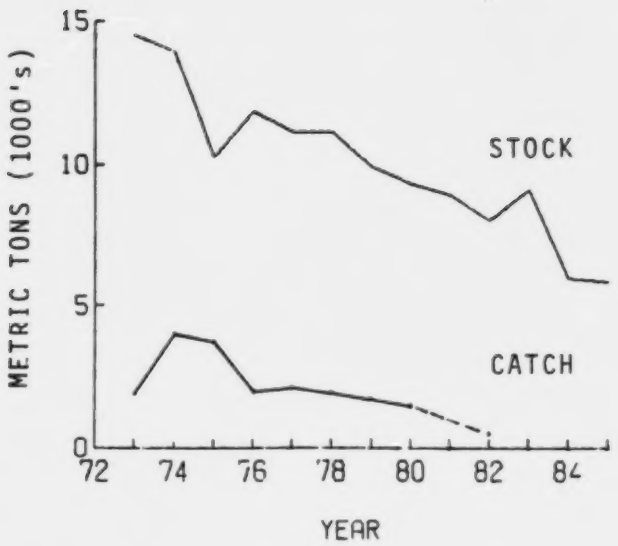

Fig. 1. Stock biomass (spawning escapement plus catch) and catch estimates from Washington's Strait of Georgia Pacific herring.

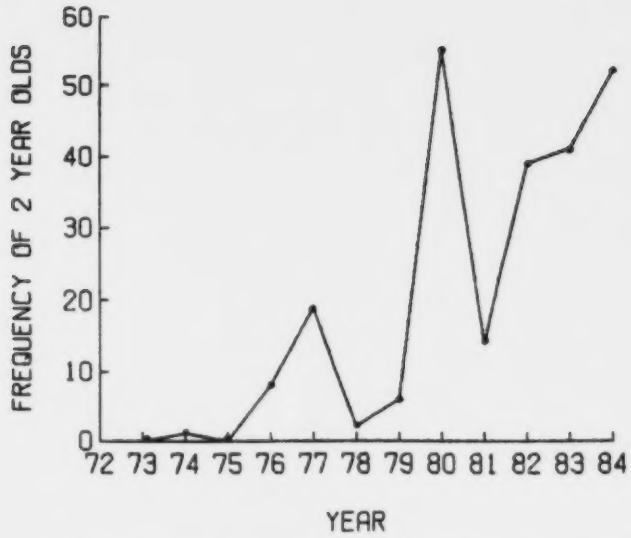

Fig. 2. Two-year-old fish as a proportion of total number of mature fish.

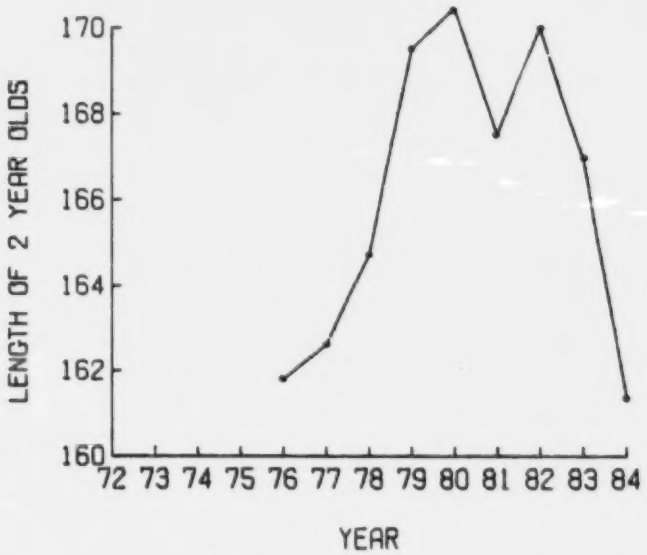

Fig. 3. Average length of two-year-old herring.

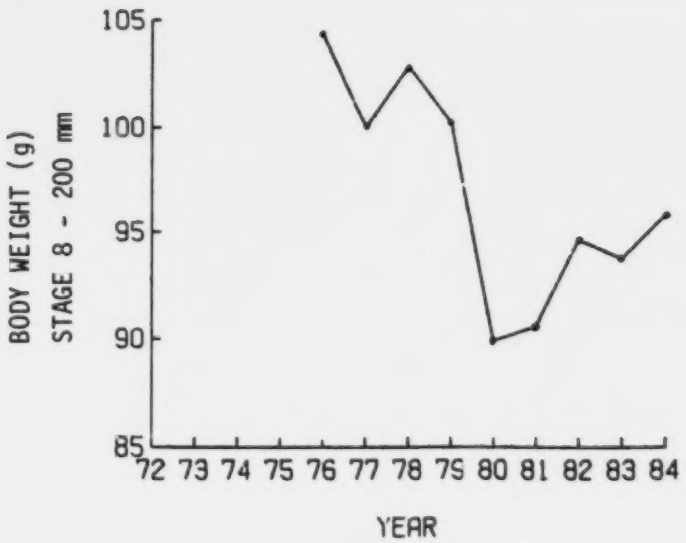

Fig. 4. Condition indicator versus year.

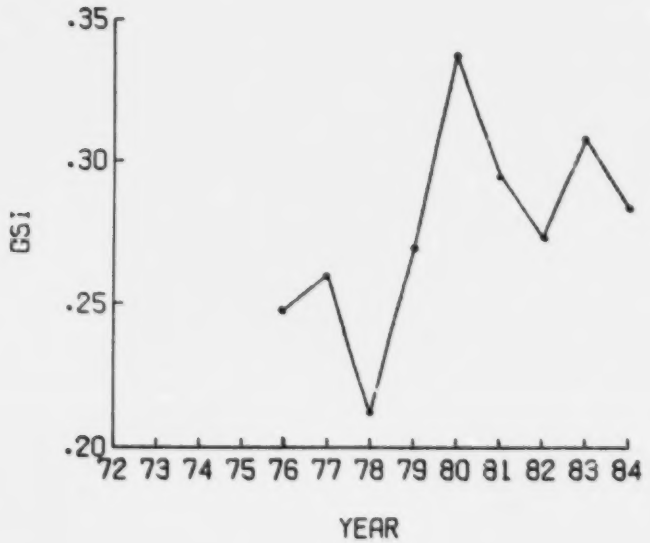

Fig. 5. Gonad somatic index versus year.

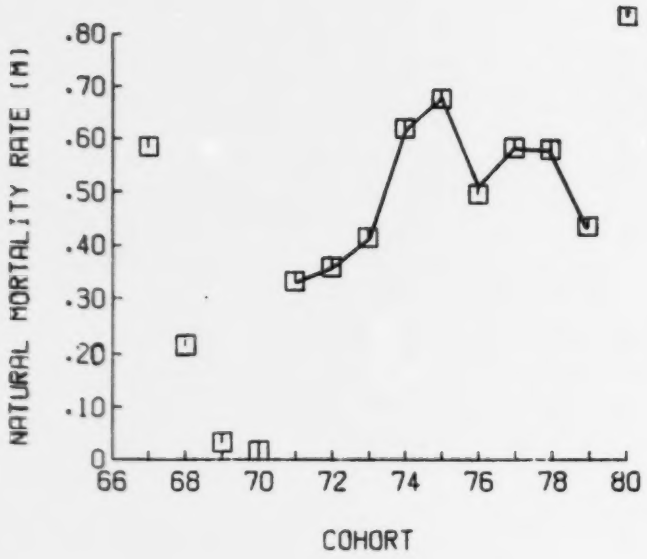

Fig. 6. Cohort specific natural mortality rate.

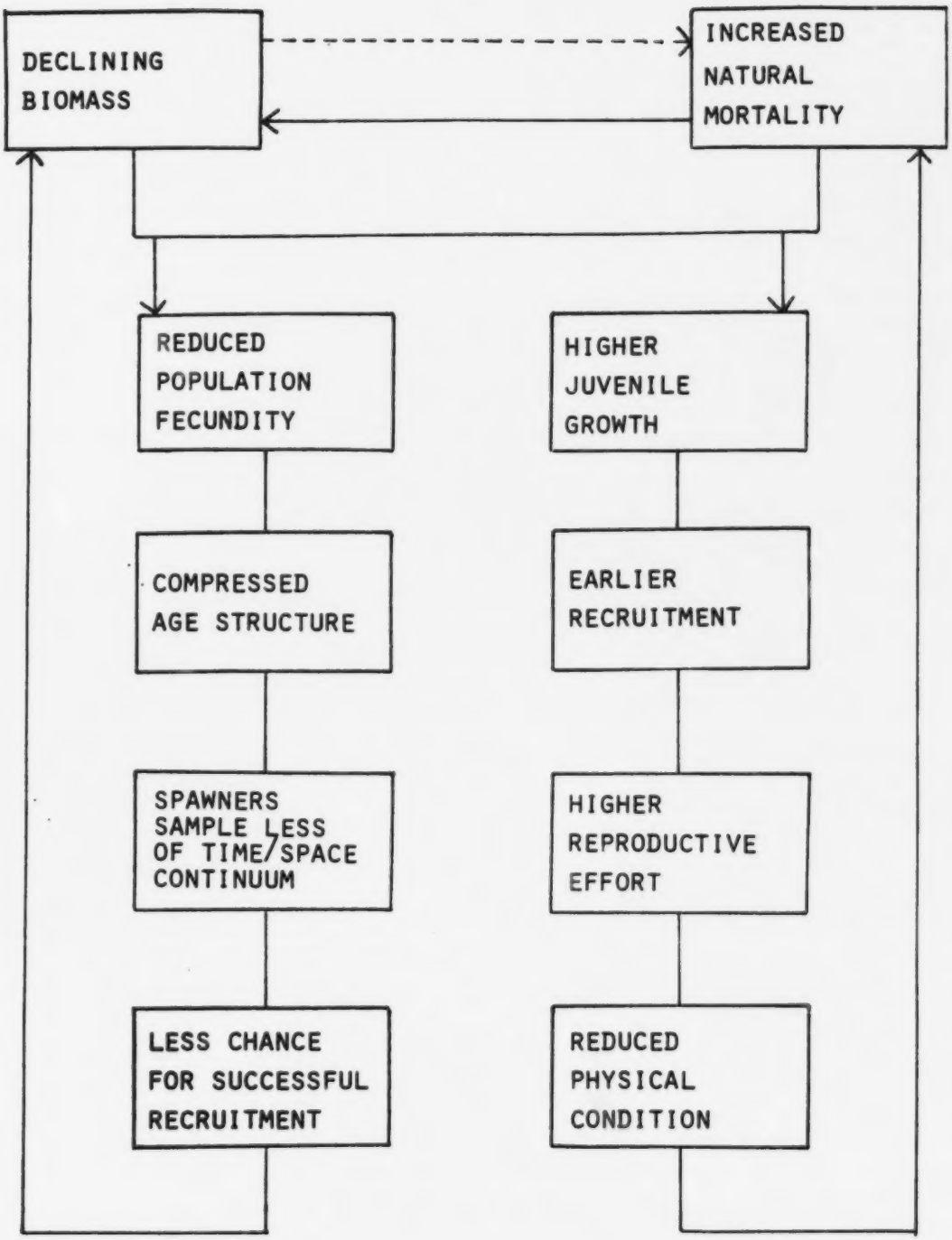

Fig. 7. Schematic diagram of recent changes and potential feedback mechanisms affecting the Strait of Georgia herring.

Environmental - dependent Ricker stock - recruitment models for Pacific herring (Clupea harengus pallasi)

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Pacific Biological Station
Nanaimo, B.C.

INTRODUCTION

There are complex mechanisms that cause fluctuations in recruitment of Pacific herring (Clupea harengus pallasi). The magnitudes of recruitment have been highly variable over the period of 1951-1982 (Fig. 1). This is an attempt to forecast year class strengths in the face of varying environmental conditions that affect the relationship between spawning stock and recruitment. I postulate that deviations from average recruitment are attributable mainly to changes in density-independent mortality due to environmental conditions. A modification to the Ricker spawning stock-recruitment model is used to forecast recent herring year class strengths (Tang 1985).

ENVIRONMENTAL-DEPENDENT RICKER STOCK-RECRUITMENT MODELS

Ricker (1954) described the spawning stock-recruitment relationship as:

$$(1) \quad R = \alpha \cdot S \cdot \exp(-\beta \cdot S)$$

where R is recruitment, S is spawning stock, α is the density-independent mortality, and β is related to density-dependent mortality, and specifies the replacement spawning stock size. In this application, parameter β is assumed to be stable over time, and thus characteristic of a stock. It is therefore assumed that deviations from predicted recruitment are attributable to changes in the α parameter over time, and α is considered to be a function of environmental conditions:

$$(2) \quad \alpha'(t) = g[X_1(t), X_2(t), \ldots, X_m(t)]$$

Where $X_i(t)$ is an environmental factor at time t (i.e. sea surface temperature), and $\alpha'(t)$ is an index of environmental conditions affecting density-independent mortality at time t (Tang 1985).

Substituting (2) into (1) yields a modified Ricker stock-recruitment model, which forms the basis for forecasting herring year class strengths:

$$(3) \quad R(t) = g[X_1(t), X_2(t), \ldots, X_m(t)] \cdot S(t) \cdot \exp(-\beta \cdot S(t))$$

RECRUITMENT AND ENVIRONMENTAL FACTORS

To select significant environmental factors for inclusion in (3), I used the technique of "exploratory correlation" (Ricker 1975; Stocker et al. 1985). I correlated the recruitment estimates from the age structured model (Haist et al. 1985) with monthly mean values of environmental factors thought important in the early life history of Pacific herring. Environmental factors analysed for the five herring populations included monthly means of sea surface temperature, sea level, salinity, river discharge, and transport. Of the five populations analysed, significant correlations were found only for three populations: Strait of Georgia / Johnstone Strait (Table 1), west coast of Vancouver Island (Table 3), and Prince Rupert district (Table 5).

FORECASTING HERRING YEAR CLASS STRENGTHS

Spawning stock and recruitment data (Haist et al. 1985) have been fitted to equation (1) to obtain estimates for α and β for the three populations: Strait of Georgia / Johnstone Strait, west coast of Vancouver Island, and Prince Rupert district. Estimates of the index of environmental conditions $\alpha'(t)$ were computed from:

$$(4) \quad \alpha'(t) = (R(t)/S(t)) \cdot \exp(\beta \cdot S(t))$$

using the above estimates of β.

The relationship between $\alpha'(t)$ and the environmental factors (Tables 1, 3 and 5) for the three populations is assumed to be linear:

$$(5) \quad \alpha'(t) = a_0 + \sum_{i=1}^{m} (a_i \cdot X_i(t))$$

The parameters a_0 and a_i were estimated by multiple linear regression for the Strait of Georgia / Johnstone Strait (Table 2), west coast of Vancouver Island (Table 4), and Prince Rupert district (Table 6). These parameter estimates were used with the most recent estimates of spawning stock size, and environmental variables to forecast year class strengths. Forecast year class strengths for the three populations are:

(1) Strait of Georgia / Johnstone Strait

Year class	Strength
1983	poor
1984	poor

(2) west coast of Vancouver Island

Year class	Strength
1982	average
1983	average
1984	average

(3) Prince Rupert district

Year class	Strength
1983	good
1984	good

Categories were determined as follows:

Poor	lowest	25% of years
Average	middle	50% of years
Good	highest	25% of years

Using the above model (eq. 3), fluctuations in herring recruitment are explained as depending on both the spawning stock size and the environmental conditions.

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Tang, Q. 1985. Modification of the Ricker stock recruitment model to account for environmentally induced variation in recruitment with particular reference to the blue crab fishery in Chesapeake Bay. Fisheries Research 3: 13-21.

Table 1. Correlation coefficients of environmental variables with recruitment estimates for the Strait of Georgia/Johnstone Strait herring population. SST, February-March mean sea surface temperature, Entrance Island; FRASER, February-March mean discharge, Fraser River at Hope; SLEV, November-December mean sea level, Point Atkinson.

Variable	N	r	$\hat{F}$ (df)	$P(F>\hat{F})$
SST	32	-0.383	5.15 (1,30)	0.031
FRASER	32	-0.339	3.91 (1,30)	0.057
SLEV	32	-0.443	7.32 (1,30)	0.011

Table 2. Parameter estimates (a_i) from multiple regression model for the Strait of Georgia/Johnstone Strait for the period 1951-1982. ($\hat{F}(3,28)=3.49$), $P(F>\hat{F})<0.029$, $r=0.522$)

Variable	Coefficient	t-ratio	P(two-tail)	
Intercept	a_0=125.6130	2.73	0.011	
SST	a_1= -3.6800	-2.07	0.048	
FRASER	a_2= 0.0015	0.36	0.722	NS
SLEV	a_3=-29.0105	-1.99	0.056	

NS = Not Significant

Table 3. Correlation coefficients of environmental variables with recruitment estimates for the West Coast of Vancouver Island herring population.
SST, February, April, September-December mean sea surface temperature, Amphitrite Point;
SAL, March mean salinity, Amphitrite Point;
SLEV, June-July mean sea level, Tofino.

Variable	N	r	$\hat{F}$ (df)	$P(F>\hat{F})$
SST	31	-0.643	20.52 (1,29)	< 0.001
SAL	31	-0.431	6.64 (1,29)	0.015
SLEV	31	0.374	4.71 (1,29)	< 0.001

Table 4. Parameter estimates (a_i) from multiple regression model for the West Coast of Vancouver Island for the period 1951-1981.
($\hat{F}(3,27)=12.40$), $P(F>\hat{F})<0.001$, $r=0.761$)

Variable	Coefficient	t-ratio	P(two-tail)
Intercept	a_0=351.2230	2.14	0.042
SST	a_1=-14.0361	-4.59	< 0.001
SAL	a_2= -4.7451	-2.93	0.007
SLEV	a_3=-26.0664	-0.42	0.678 NS

NS = Not Significant

Table 5. Correlation coefficients of environmental variables with recruitment estimates for the Prince Rupert District herring population. SST, May-September mean sea surface temperature, Cape St. James; TRANS, Sum of January and Febuary Ekman Transport, 54N134W; SLEV, January mean sea level, Prince Rupert.

Variable	N	r	$\hat{F}$ (df)	$P(F>\hat{F})$
SST	32	0.533	11.91 (1,30)	0.002
TRANS	32	0.671	24.57 (1,30)	< 0.001
SLEV	31	0.395	5.35 (1,29)	0.028

Table 6. Parameter estimates (a_i) from multiple regression model for the Prince Rupert District for the period 1951-1982.
($\hat{F}(3,28)=7.76$), $P(F>\hat{F})=0.001$, $r=0.674$)

Variable	Coefficient	t-ratio	P(two-tail)
Intercept	a_0=108.5180	0.61	0.547 NS
SST	a_1= 8.1320	1.86	0.073
TRANS	a_2= 0.0954	2.90	0.007
SLEV	a_3=-49.7496	-1.07	0.294 NS

NS = Not Significant

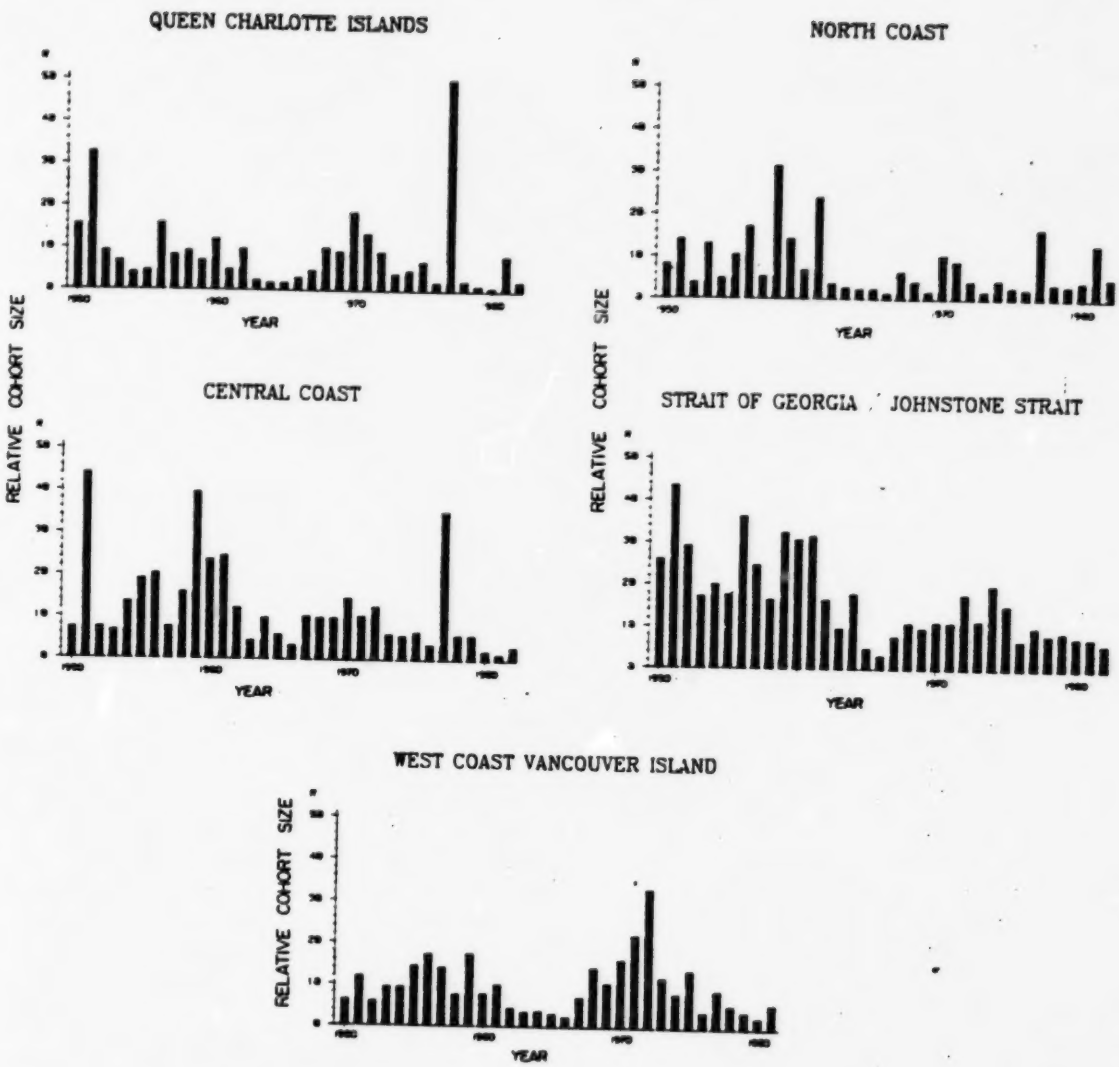

Fig. 1. Relative cohort strengths from age-structured model analysis, 1950-1982. (Source: Haist et al. 1985).

Compensatory mortality in Pacific herring eggs

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Surveys conducted within Washington State herring spawning grounds indicate that spawn intensity decreases significantly before hatching. Observations of large flocks of ducks and gulls around the spawning areas after large spawning events suggest that predators may cause much of the egg loss. The magnitude and causes of herring egg mortality were investigated within two spawning populations of Washington State herring. Two components of egg mortality were investigated: egg loss and egg inviability rates were estimated by monitoring egg cohorts during their incubation period.

METHODS

After a spawning was detected, study plots measuring 1.5 m by 1.5 m were established. Each study plot was sampled after establishment and every two to four days thereafter until hatching began. Eight to ten random subsamples were removed from a plot during each sampling by removing the rooted egg-laden vegetation and anchored eggs within a 0.0225 m^2 quadrat. The vegetation and eggs were placed in a sample bag and preserved in Stockard's solution until laboratory processing. Sampling procedures were designed to be conducted during low spring tides exposing intertidal spawning grounds or conducted while sampling submerged plots using SCUBA techniques.

Laboratory processing included enumerating the eggs within each sample and determining the proportions of egg cases and dead eggs to normal eggs. The eggs were either directly enumerated or subsampled by gravimetric methods of plankton-splitting. Dead eggs were defined as eggs that were opaque white.

The causes of egg mortality were investigated by documenting predator abundances within the spawning grounds, excluding predators from study plots, and estimating predator consumption rates of eggs. The abundances of birds within the spawning ground were estimated weekly during the spawning season, and the numbers of ducks and gulls within two hundred meters of a study plot were counted on a near daily basis. Exclusion cages were placed around some study plots preventing predators larger than 12 mm in diameter from entering the cages. Egg mortality rates were estimated within the cages and compared to nearby natural mortality plots. Predator inclusion studies were conducted in the field and in the laboratory by enclosing known quantities of herring eggs in screened chambers containing potential invertebrate predators.

RESULTS

Five cohorts of eggs were monitored at a winter spawning site in Quartermaster Harbor. Two cohorts of eggs were monitored at a spring spawning site at Birch Bay in the southeastern Strait of Georgia. Initial plot densities ranged from 392 eggs$\cdot m^{-2}$ to 15022 eggs$\cdot m^{-2}$ at Quartermaster Harbor and from 8297 eggs$\cdot m^{-2}$ to 3697000 eggs$\cdot m^{-2}$ at Birch Bay. In all plots studied, egg densities declined from spawning to hatching ($P<0.05$; Fig. 1). The egg loss rates fit exponential models of decline better than linear models. Instantanteous daily egg loss rates ranged from 0.186 to 0.834, corresponding to 16.9% to 56.6% eggs lost per day. The variability of egg loss rates between study plots was best explained by a compensatory mortality model: as initial plot densities increased, so did their egg loss rates (Fig. 2).

The dead egg ratio within the study plots increased from 1.5% just after spawning to at least 10% just before hatching (Fig. 3). The dead egg ratio measured just before hatching (the terminal dead egg ratio) was higher (to 21.6%) in those plots experiencing intertidal exposure than those plots always submerged during incubation.

The egg loss rate calculated over the incubation period and the terminal dead egg ratio were multiplied by one another to yield an estimate of the total survival rate. The total survival rate ranged from 0.02% to 4.87% and also followed a compensatory pattern (Fig. 4). The total survival rate was dominated by the egg loss rate. Multiplying the total survival rate for each plot by the spawning egg density for the plot yielded an estimate of the larval production rate for that plot. Larval production rates ranged from 1.2 larvae$\cdot m^{-2}$ to 1419.2 larave$\cdot m^{-2}$ (Fig. 5). Within each spawning area, larval production was not maximal within the plots with the greatest initial egg densities but in the plots with low spawning densities.

Excessive wave surge or currents were not encountered during the incubation periods of the studies cohorts. The presence of birds, fishes, and invertebrates feeding on eggs around the spawning grounds and study plots indicated that predation was the significant source of egg loss. Duck and gull abundances within the spawning area tracked the level of spawning activities, and the numbers of ducks present around the study plots tracked the loss of eggs from the same study plots (Fig. 1).

Six predator exclusion experiments were conducted, only half of which had egg loss rates within the cages less than the natural mortality rates of nearby uncaged plots (Fig. 6). In those experiments, daily egg loss rates were reduced only 20.9% to 49.7%. Observations and experimentation revealed that the exclusion experiments were biased. Small snails and amphipods were able to enter the cages and feed upon herring eggs in a predator free environment. Predator inclusion studies revealed that individual snails and amphipods could consume 5.6 eggs and 4.4 eggs each day, respectively. Density estimates of these predators indicated that they alone may account for most of the egg loss in lower density plots.

DISCUSSION

Complete or near complete egg loss has been documented in Pacific coast spawning grounds (see Palsson 1984 for review), and is primarily attributed to predation. Egg loss rates in herring spawning grounds may be problematical; egg loss rates are a function of egg densities and the predators attracted to the spawning area.

The compensatory mortality pattern suggests that spawning grounds within typically high egg densities may not be the only critical spawning habitat within a spawning ground. Since larval production is greatest in moderate density plots, habitat managers must consider the value of all herring spawning habitat before making decisions on alternate usage of the spawning areas. High egg loss rates also must be recognized by herring managers as they assess egg resources: any delay between spawning and surveying may cause an underestimate of spawning biomass.

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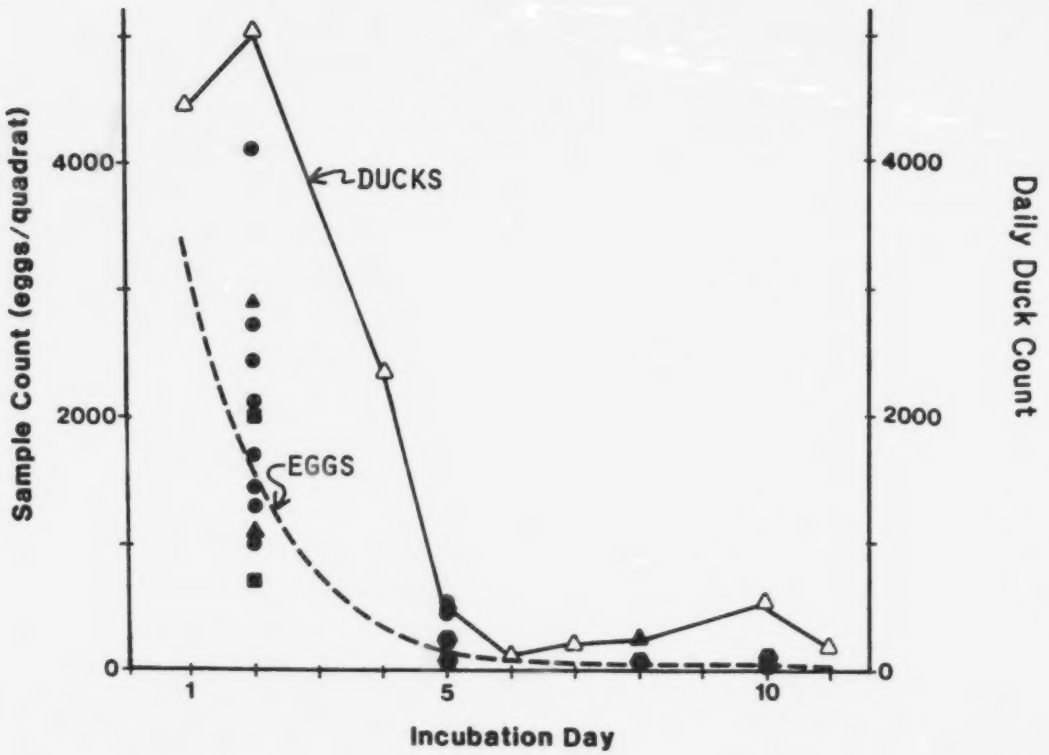

Fig. 1. The decline of egg and duck abundance in and around a study cohort at Birch Bay. This pattern is typical of most cohorts studied.

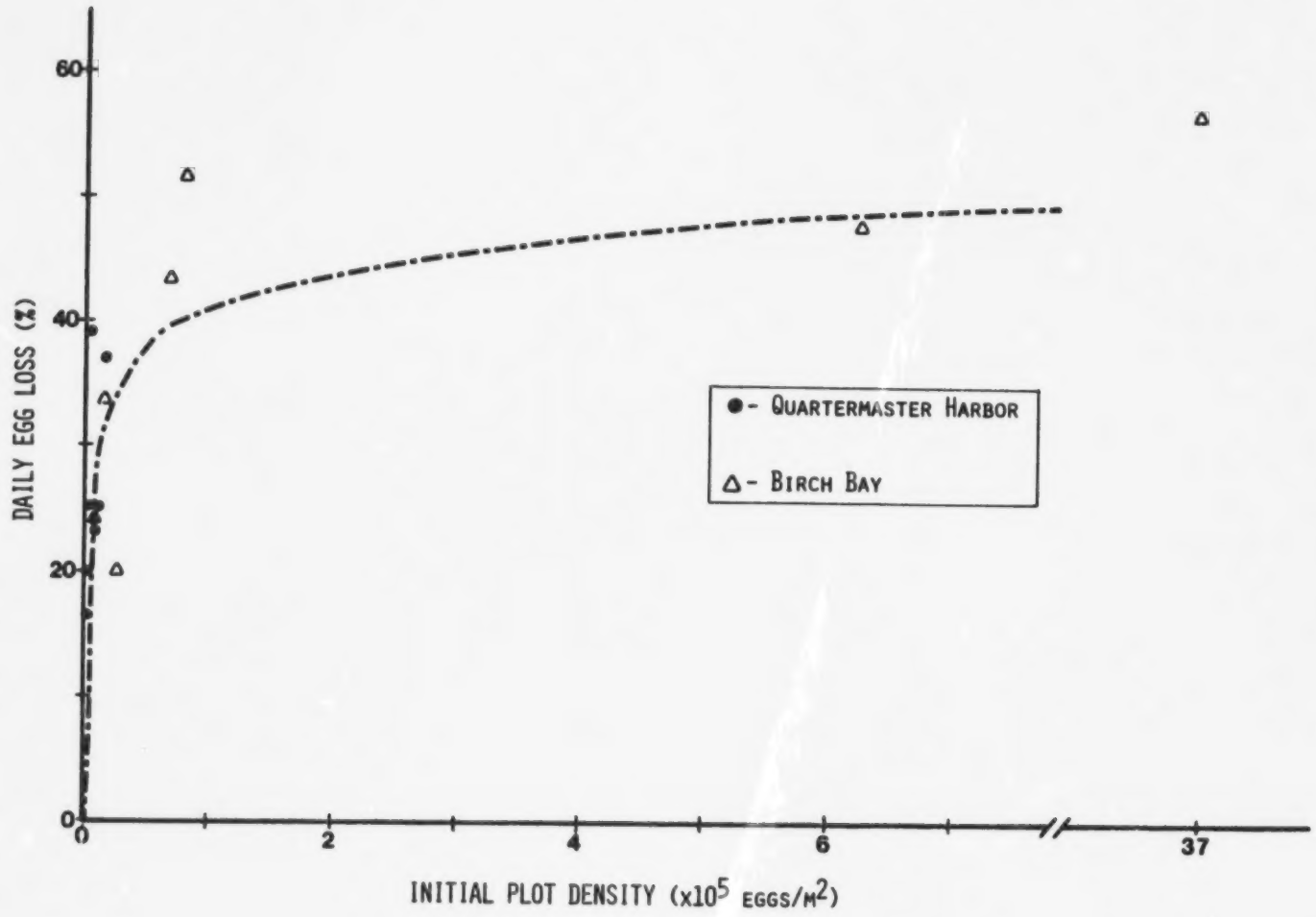

Fig. 2. The compensatory mortality relationship observed from herring egg cohorts.

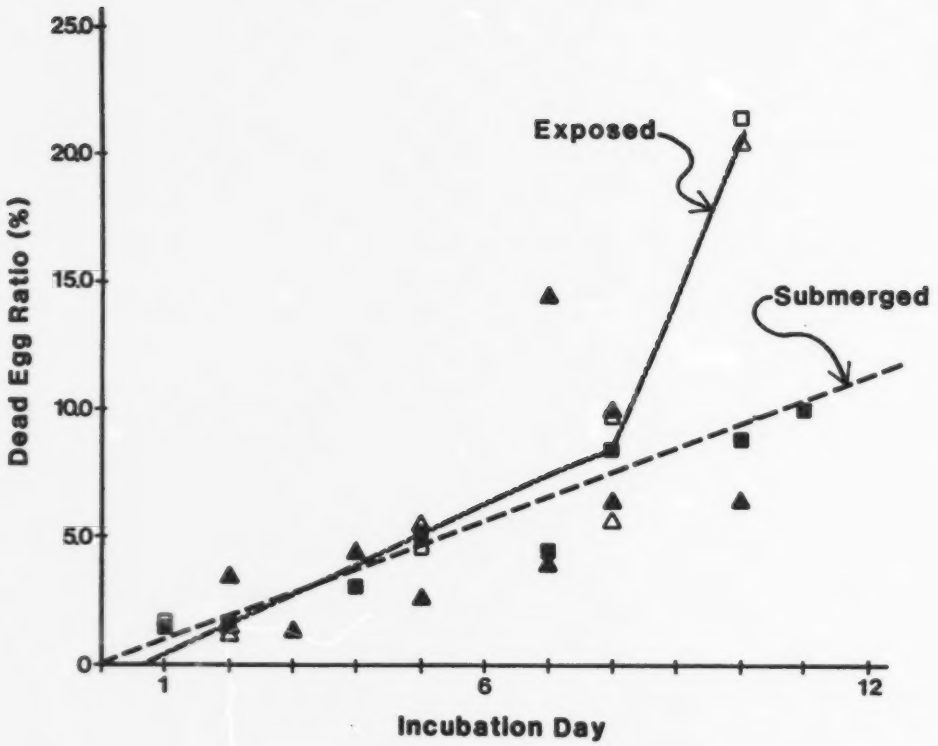

Fig. 3. Increasing dead egg ratios from submerged (solid figures) and exposed (open figures) egg cohorts from Quartermaster Harbor and Birch Bay.

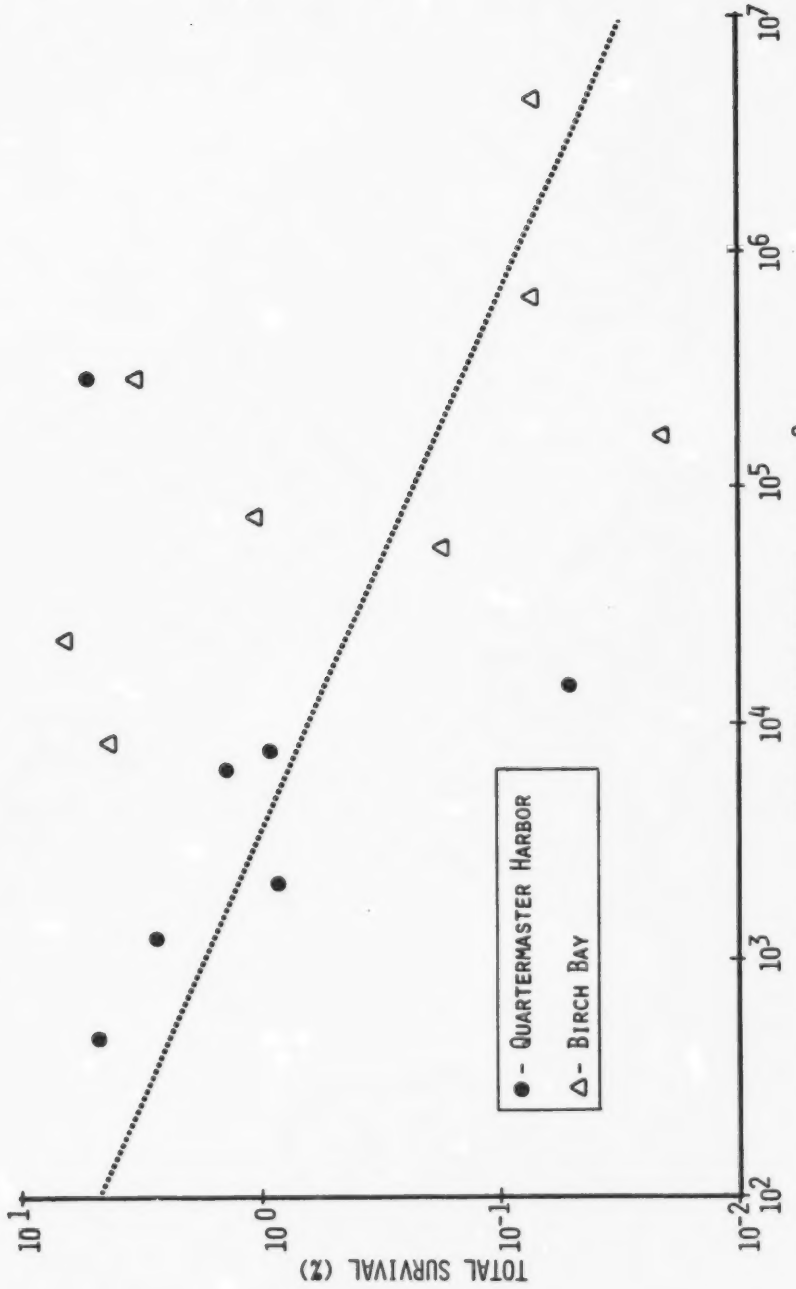

Fig. 4. The compensatory relationship of total egg survival in herring spawning grounds.

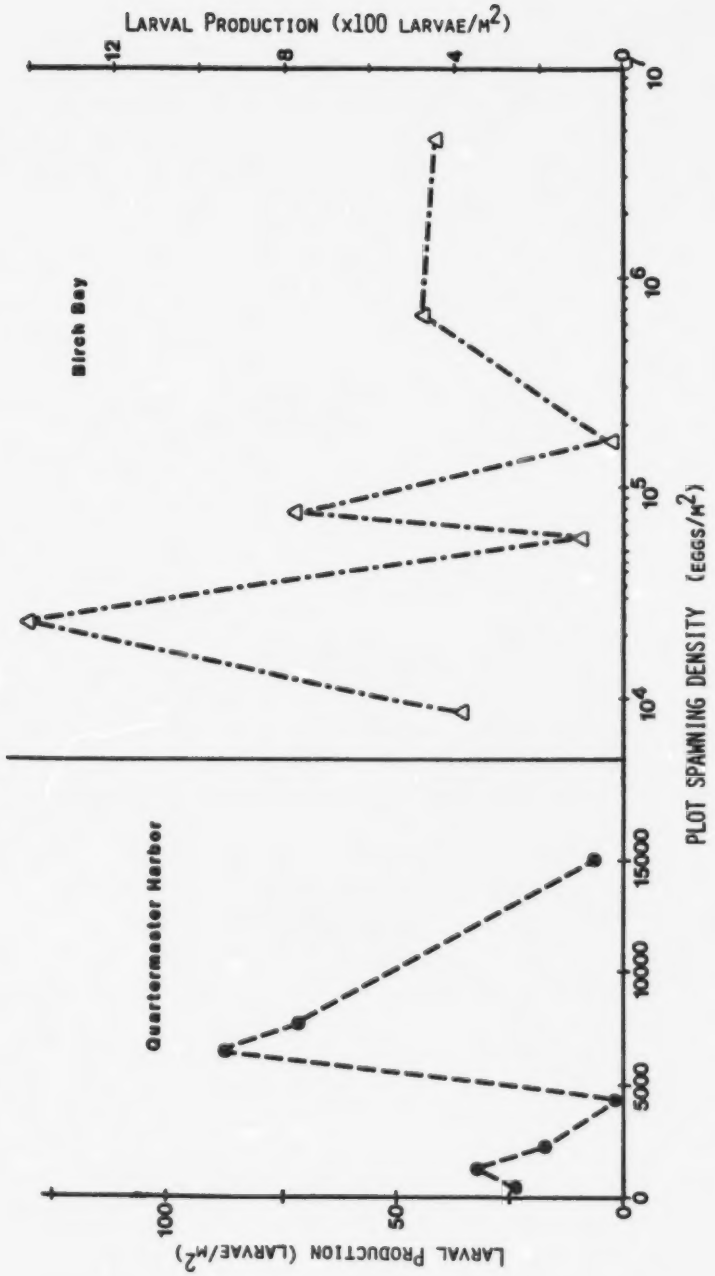

Fig. 5. Larval production from study plots at two Washington herring spawning grounds.

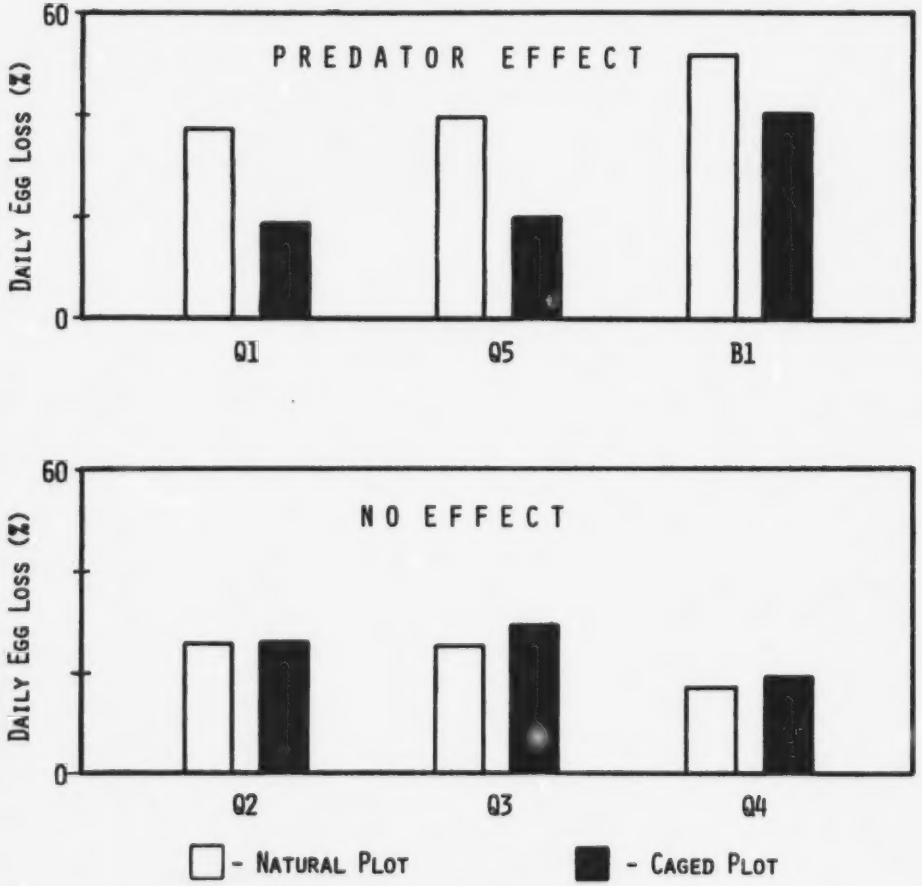

Fig. 6. Predator exclusion results from six experiments conducted at two herring spawning grounds.

Developing herring embryos exposed to oil in seawater

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INTRODUCTION

The annual harvest of herring roe-on-Fucus in the intertidal region in Bristol Bay is associated with intense activity over a relatively short period of time. In 1984 there were over 300 registered pickers for herring roe-on-Fucus (Lebida et al. 1984). The openings for harvesting roe-on-Fucus typically are less than 48 hours and are typified by a large concentration of pickers in one intertidal area. Most of the pickers arrive on the grounds in small skiffs powered by outboard motors. This intense activity leads to the possibility of oil and gasoline spills in or near the intertidal.

It has been reported that developing herring embryos and larvae are sensitive to components found in outboard and diesel fuel (Cameron and Smith 1980; Linden 1976; Smith and Cameron 1979; Struhsaker et al. 1974). The possibilities of having such spills and the visual sightings of oil slicks in the intertidal during the times of harvest led to the present investigation of the effects of outboard gasoline in seawater on developing herring embryos.

METHODS

In May of 1984 several female and male Pacific herring (Clupea harengus pallasi) were artifically spawned to produce layers of fertilized eggs on plastic and glass strips. The fertilized eggs along with a natural spawn on Fucus sp. were placed into a flow through dosing system of seawater mixed with various concentrations of outboard gasoline (50:1 v/v regular gasoline:outboard oil). Flow rates were maintained at 1.0 liter per minute. An unoiled control and five oiled doses were run. The water accommodated fraction (WAF) had concentrations of (1) 0.06, (2) 0.16, (3) 0.28, (4) 1.8, and (5) 4.8 parts per million (ppm) total hydrocarbons in seawater.

Herring eggs were either exposed for 16 days or for just the first two days to the WAF doses. At the time of hatching, after Day 16, a portion of the 16 day exposed eggs were transferred to clean seawater and a portion left in the WAF doses to measure hatching success.

Parameters that were measured on the developing herring eggs included hydrocarbon uptake and depuration, percentage dry weight, respiration rates, mortalities, developmental rates, and hatching success. The hatched larvae were assayed for hydrocarbon content, respiration, and LC-50.

RESULTS AND DISCUSSION

The herring eggs appeared to take up and concentrate up to 100-fold the hydrocarbons from the WAF doses (Fig. 1). Eggs transferred to clean seawater slowly released the accumulated hydrocarbons although aliphatics were not released as quickly as aromatics.

Respiration rates generally increased with stage of development (Fig. 2). Eggs exposed to 4.8 ppm showed little increase in respiration rates. Eggs exposed to 1.8 ppm showed increased rates of respiration until Day 4 at which time the rates began to decline.

Mortalities were nearly 100% by Day 12 for those eggs exposed to 4.8 ppm WAF. The lower doses showed no differences in mortalities when compared to controls, although all groups had relatively high mortalities (30-50%) by the end of the exposure period (Day 16).

Dry weight percent generally declined for all groups over the development period from a value of 15-16% at fertilization to less than 15% by Day 16. All groups showed a transient increase in dry weight at Day 4, corresponding to the late neurula stage.

It is at the late neurula stage that the eggs in the highest dose (4.8 ppm) stopped developing. The eggs in the next highest dose (1.8 ppm) also showed arrested development at the same stage, but were later able to catch up to the development of the controls by Day 14 just prior to hatching.

Hatching success was dependent on the dose with the exception of low hatching success in the controls. Hatching success was 28% for the eggs in the lowest dose. This number declined with increasing dose concentration to 0% hatching in the 4.8 ppm dose.

The hatched larvae appeared to be unaffected by prior exposure to the hydrocarbons. In fact, almost all traces of outboard fuel were lost by the larvae upon hatching. This result indicates that most, it not all, of the hydrocarbons are concentrated in the chorion.

Larval respiration rates were unaffected by exposure to outboard fuel for short time periods. But the 48 hours LC-50 for newly hatched herring larvae was found to be 0.60 ppm. This compares to an LC-50 for three week old pink salmon larvae of 1.9 ppm outboard fuel in seawater.

In summary, the herring eggs take up and concentrate outboard fuel in seawater in the chorion of the egg. This accumulation appears to have little effect on the development and well-being of the embryos up to the time of hatching for exposures below larval LC-50 dose level. Low levels of hydrocarbons (less than 50 ppb) in the intertidal waters are probably not a concern with respect to herring embryo development.

ACKNOWLEDGMENTS

This work was partially funded by an RSA from the Alaska Department of Environment Conservation. I would also like to acknowledge the help of the National Marine Fisheries Service Auke Bay Laboratory in providing space for the dosing tanks, and in performing the hydrocarbon analyses.

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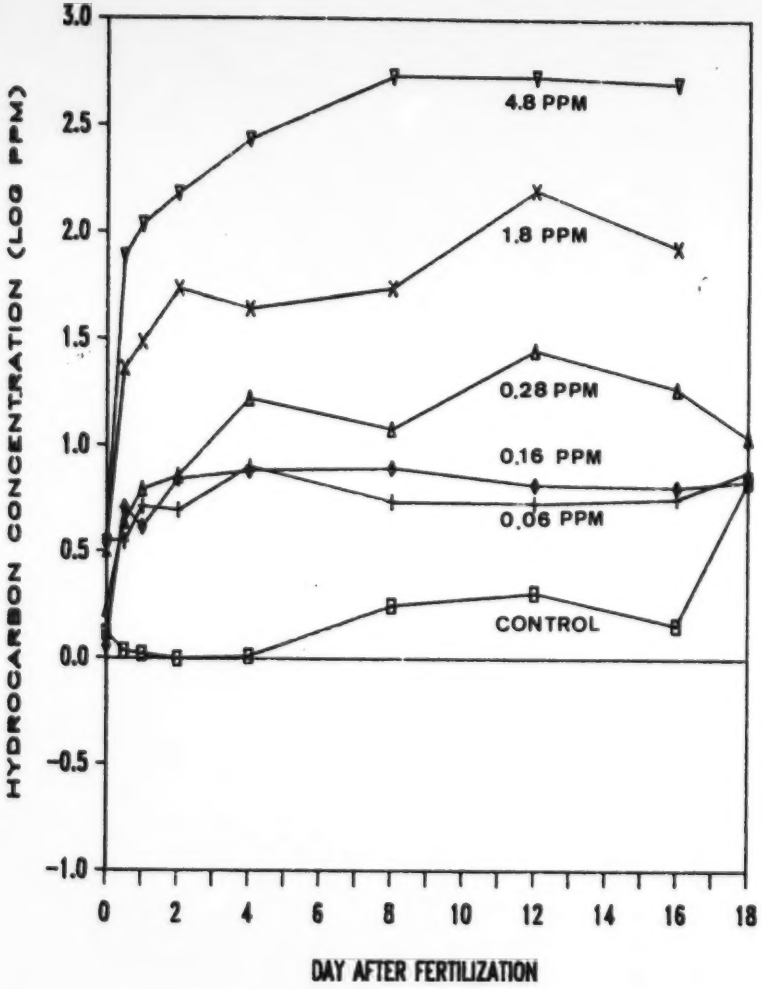

Fig. 1. Accumulation of low molecular weight aromatic hydrocarbons by herring eggs exposed to outboard fuel in seawater. Doses range from 0.0 to 4.8 parts per million (PPM). Day 16 is the last day of exposure. Values for Day 18 are for hatched larvae.

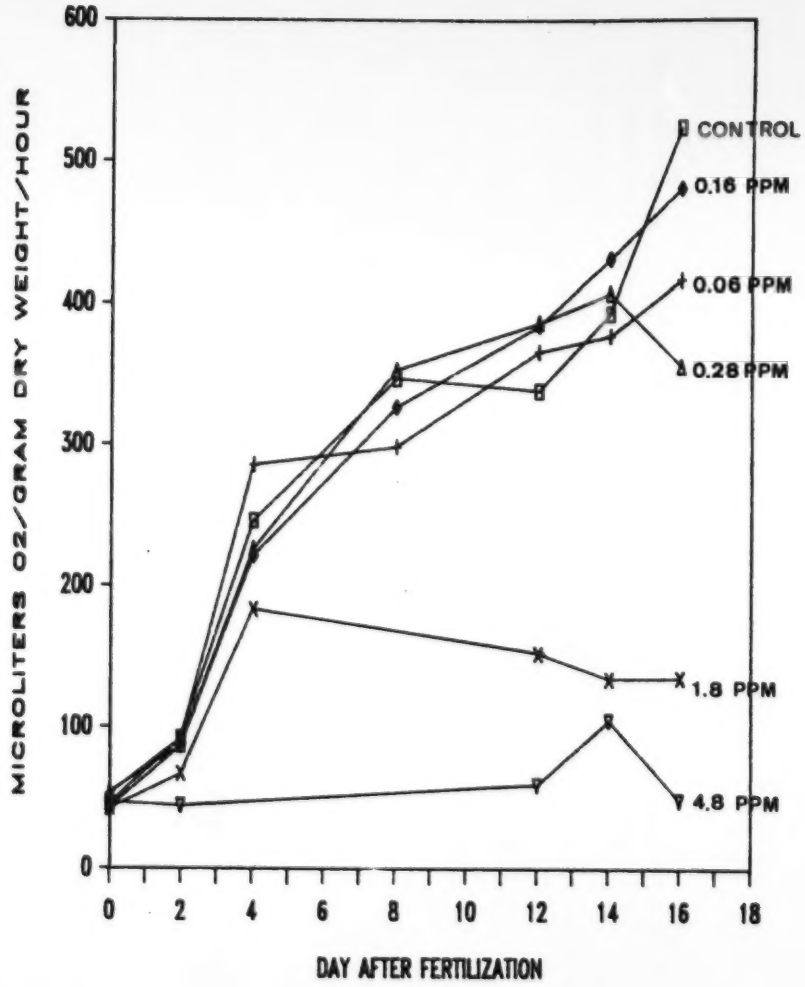

Fig. 2. Respiration rates of developing herring larvae exposed to outboard fuel in seawater. Doses and exposure days are same as in Figure 1.

Jellyfish as predators of larval herring at spawning grounds in British Columbia

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The following briefly summarizes the major conclusions of a 3-year study undertaken to determine the importance of soft bodied zooplankton as predators of larval fishes. The impact of gelatinous predators on fish larva populations has been found to be substantial where determined previously (Moller 1980, 1984; Purcell 1981, 1984). The goals of the present research were to identify important predators and to estimate predation rates *in situ*. The yearly objectives were: (1) in 1983 to examine predation throughout the spring, (2) in 1984 to examine geographic variations in predation, (3) in 1985 to estimate the percentage of the disappearance of hatching larvae that could be attributed to predation, and to compare predation impacts over the duration of the study. Two herring spawning grounds on Vancouver Island were sampled in 1983-85 (1) the Lambert Channel/Baynes Sound, (2) and the Kulleet Bay/ Yellow Point areas. Eighteen additional sites were sampled in 1984 on Vancouver Island, the north and south B.C. mainland coast, and on the east coast of the Queen Charlotte Islands. The same sampling gear and methods were used in all cases to insure direct comparability. Zooplankton, fish larvae, and jellyfish were sampled using a 0.75 m diameter, 0.333 mm mesh conical plankton net. Densities of large and scarce jellyfish were determined using a 1 m diameter, 3 mm mesh net. Horizontal plankton tows were made at 1 and 5 m depth, during day and night.

Jellyfish were dipped individually from surface waters and preserved immediately for later gut content analysis. The approach used throughout was to determine the number of herring larvae in each jellyfish, and to divide those numbers by the time required for digestion of a larvae. This, in combination with data on herring larva and jellyfish abundance, yielded estimates of the percentages of the larval populations being consumed.

The major conclusions are as follows:

1. *Aequorea victoria*, a hydromedusa species found to about 7 cm in diameter, was the only predator present when the herring larvae hatched in 1983 and 1985.

2. The diet of *Aequorea victoria* was predominately (up to 80%) herring larvae during hatching, and included fish larvae in 5 other families, pelagic fish eggs (Fam. Pleuronectidae), large percentages of soft-bodied prey like larvaceans, but comparatively few crustacean zooplankton.

3. Yolk sac herring larvae and those $\leq$ 12 mm were captured by *Aequorea victoria in situ*. Laboratory experiments showed that as they grew, herring larvae were increasingly able to escape from the jellyfish's tentacles. Only yolk sac larvae were captured *in situ* by the ctenophore *Pleurobrachia bachei* and the chaetognath *Sagitta* sp.

4. Predator populations differed greatly among the numerous spawning grounds sampled in 1984. Predator densities were high in bays and inlets, but low along exposed shores. Sites on the B.C. mainland coast had the lowest predator abundances (mostly the ctenophores Bolinopsis sp.), while sites in the Queen Charlotte Islands generally had abundant hydromedusae (mostly the hydromedusa Phialidium gregarium), and sites along the Vancouver Island shore had abundant hydromedusae (Aequorea victoria and Sarsia tubulosa).

5. The numbers of herring larvae found in Aequorea medusae were directly related to the larval abundance (log-log, $r = 0.88$). This provides a means of predicting predation rates in situ given only the abundances of larvae and medusae.

6. The population of Aequorea victoria in Kulleet Bay increased approximately 10-fold each year, from about $0.015 \cdot m^{-3}$ in 1983, to $0.15 \cdot m^{-3}$ in 1984, and to $1.5 \cdot m^{-3}$ in 1985. Maximum densities measured in 1985 were $17 \cdot m^{-3}$.

7. Predation by Aequorea victoria in 1985 had a devastating impact on herring larva populations in Kulleet Bay. Larval densities decreased from an average maximum of $264 \cdot m^{-3}$ to $3.5 \cdot m^{-3}$ in 3 days. Medusae were estimated to consume from 3 to 50% of the available larvae hourly throughout the 8-day sampling period.

This research was supported by a NATO postdoctoral fellowship to the author, an NSERC Strategic Grant to G. O. Mackie, and Subventions funds from the Department of Fisheries and Oceans Canada. I thank J. S. von Carolsfeld and D. Grosse for assistance in field sampling. T. D. Siferd and J.-A. Grodon for assistance in sample analysis, and G. O. Mackie and the Biology Department of the University of Victoria for their generous cooperation.

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Egg loss in British Columbia herring spawns

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Divers surveyed and sampled herring spawns in British Columbia in six years between 1975 and 1982. Information was collected on 373 transects and eggs in 2449 quadrat samples were counted.

The proportion of the spawn area and the proportion of total eggs exposed at observed tide levels during the incubation period were calculated. In the Strait of Georgia the tide ranged from +0.9 m to +5.1 m and the mean tide level was +3.2 m. Spawn above +2 m accounted for 4% of total area and 2% of total eggs and was exposed for 40% of the incubation period. About 52% of this exposure was during daylight hours, 0500 to 1700 PST, when bird predation was observed to occur. Spawn between +2 and +1 m was 13% of total spawn by area and 16% of total spawn by eggs. This spawn was exposed for 10% of the incubation period and half of this exposure was during daylight. On the west coast of Vancouver Island the tide ranged from 0.0 to +4.1 m and the mean tide level was +2.2 m. About 2% of the spawn by area and 3% of the spawn by eggs was above +2 m and was exposed for 85% of the incubation period, and 60% of this exposure was during daylight. Spawn between +2 and +1 m was 9% of the spawn by area and 10% of the spawn by eggs. This spawn was exposed for 40% of the incubation period and 70% of this exposure was during daylight. Spawn between +1 and 0 m was 16% of spawn by area and 26% of spawn by eggs and was exposed for 6% of the incubation period, and 83% of this exposure was during daylight. Tides during the incubation period ranged from +0.2 to +7.0 m on the north coast and the mean tide level was +3.9 m. Spawn above +2 m was 10% of total spawn by area and 17% of total eggs. It was exposed for 28% of the incubation period and 75% of this exposure was during daylight. Spawn between +2 and +1 m was 20% of total area and 26% of total eggs and was exposed for 11% of the incubation period with 70% of this exposure occurring during daylight. Spawn between +1 and 0 m was 16% of total area and 18% of total eggs. This spawn was exposed for 1% of the incubation period, nearly all of which was during daylight.

Egg density in samples collected throughout the incubation period was regressed against the day after mean spawning time on which the sample was collected to determine whether there was any observed decrease in egg density with time. Correlations were generally poor with r-squared between 0.0% and 2.6%. For spawn that was exposed during the incubation period, above +1 m for the Strait of Georgia and above 0 m for the west coast of Vancouver Island, egg density increased slightly during the 14 day incubation period in the Strait of Georgia from 220 to 243 eggs$\cdot m^{-2}$ and decreased considerable on the west coast of Vancouver Island from 777 to 185 eggs$\cdot m^{-2}$. For spawn that was not exposed during the incubation period, egg density decreased substantially in the Strait of Georgia from 360 to 149 eggs$\cdot m^{-2}$ and slightly on the west coast of Vancouver Island from 500 to 412 eggs$\cdot m^{-2}$. This analysis was not done for the north coast because there were insufficient samples collected there.

The decrease in egg density during the incubation period can be attributed to predation and egg removal from the substrate by wave action. However, there may be some confounding effects in the data used for this analysis. It was documented in the 1983 Strait of Georgia survey that egg density is highest near the centre of spawns and some of the spawns were surveyed from the centre towards the ends. Also, larger and denser spawns were frequently surveyed before smaller and lighter spawns. Predation in the intertidal zone is thought to be mostly by seagulls and other shore birds. Diving ducks, mostly scoters in British Columbia, probably eat some of the spawn deposited subtidally. Other predators have not been identified but probably include starfish, snails, amphipods, crabs, and fishes. Egg loss due to wave action has been shown to be 26% in stormy weather. Calculations based upon reasonable assumptions about bird populations and rations show that it is unlikely that birds consume more than 5% of total herring spawn in British Columbia.

SESSION 5

STOCK IDENTIFICATION

A stock hypotheses based on spawn and winter distribution

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The prerequisite of geographic isolation for genetic divergence and reproductive isolation among populations is well established (Mayr 1963). Probably a partial degree of geographic isolation or separation is also the basis for divergence of distinct populations of fish stocks. The hypothesis presented here is that Pacific herring stocks can be defined on the basis of the geographic distribution of their spawning locations. This assumption is consistent with the hypothesis of Iles and Sinclair (1982) which maintains that the physical and biological characteristics of the larval retention areas are the basis for stock separation, stock size and spawning times of Atlantic herring stocks: large retention areas can generate large stocks and vice versa. Further, the timing of spawning for each stock is adapted to the timing of the local production cycle as suggested by Cushing (1975). In view of these considerations a useful definition of the word "stock" that can apply to Pacific herring is "a population that maintains and sustains itself in a definable area" (Booke 1980). Such a definition does not preclude movements or migrations within or between areas during the non-spawning period, but it does require that spawning locations be confined to within the retention areas and that spawning times are adapted to that location. It also requires that herring must "home" to their respective spawning locations.

Spawn records of herring, from 1928 to 1984, were examined for all locations of the British Columbia coast to determine if their geographical configuration and the timing of spawn could be used as the basis for distinguishing among different stocks. Since the spawn record collection began in 1928, over 1200 different locations on the British Columbia coast have been documented as spawning sites. Many of these locations are "clustered" into a smaller number of distinct geographic entities, such as bays, inlets, islands, etc. Hourston and Hamer (1979) provide a useful geographical categorization system that divides the British Columbia coast into approximately 115 different "sections" which are themselves subdivisions of a series of larger statistical area used by the Department of Fisheries and Oceans for catch record analyses and management.

Within each section the temporal continuity of spawns were analysed and classified as one of the following:

1. continuous - spawns occurred every year without a break;

2. continuous except for short gaps - a continuous spawning record except for a gap or gaps in the records (a gap in the records could consist of a break of not more than three years);

3. discontinuous - spawns occurred in the area but were interrupted frequently by years with no spawning and had time gaps of more than three years;

4. intermittent or negligible - spawns occurred rarely or only for a short period with long periods of absence.

This classification was supplemented with information on the timing of spawns within each section. Available information on winter distributions and larval distributions was also considered. Also, in remote locations, there is an additional problem of incomplete records at times. These incomplete records cannot be distinguished from periods with no spawning. Therefore, in a few instances, gaps in the spawning records were considered to reflect the incompleteness of the records rather than the absence of spawning.

Using only the criterion of continuous spawns over time, a total of 40 geographical groupings were classified as having consistent records of spawn over time. Some geographical groupings consist of a single section; others consist of several sections. There were no instances of more than one grouping within a section. The estimate of 40 should be regarded as an extreme high representing the maximum number of possible stock configurations. It is likely that the actual number is lower and when the additional information on spawn timing and winter distributions are considered the estimate is reduced to 23. Of these, only 8 are large enough to support sustained fisheries and represent the main locations used by the present roe fisheries and past reduction fisheries. In this respect, this analyses is consistent with the stock groupings used for the present management of British Columbia herring. Another 8 stocks are large enough for small or intermittent exploitation (such as roe-on-kelp operations or local bait fisheries) but not for sustained participation in the major fisheries. The remaining 7 stocks are very small and probably should never be systematically exploited.

The numbers of stocks presented here should not be regarded as fixed; rather the intent is to identify the maximum number of components that could represent discrete stocks. It will take further work using other techniques (i.e., biochemical and morphometric techniques, etc.) to add greater resolution and discrimination to the outline presented here.

It is also clear from the analysis that stock structures are not necessarily static. Certain locations do not support continuous spawnings; rather it appears that they are used repetitively for periods of 5-10 consecutive years followed by longer periods with no spawnings. One example, among many available, is Goldstream Flats in Saanich Peninsula. A Fisheries Inspection Officer, SGD. Scott reported a spawn on Goldstream Flats in 1932. This was the first spawn he had observed in that location and when making enquiries among older residents of Saanich peninsula learned that it was the first time in 50 years that herring had spawned there. Herring spawned again in Goldstream Flats, an area only several km in length, at four later periods; 2 consecutive years from 1944-45, 4 consecutive years from 1948 to 1951; 9 consecutive years from 1954 to 1962; and in 1964. No spawns have been reported in Goldstream Flat since 1964 and no spawns have occurred elsewhere in Saanich Inlet since 1982. Of the more than 26,000 km of the British Columbia coastline, 4346 km have been documented as having received some herring spawn at some time from 1928 to 1984. The fact that a few km of spawning area in Goldstream Flats was used repeatedly for a number of years

indicates that the spawning on that site did not occur randomly; rather, the incidence of the first spawns appears to increase the probability of further spawns in subsequent years. Such an event could occur only through homing mechanisms. It seems very likely that for a number of years herring homed to the precise location of Goldstream Flats to spawn. It is equally clear that the spawning run which developed there was not permanently established, either within the Goldstream Flats location or any of the nearby adjacent spawning locations identified within Saanich Inlet.

Many similar examples of repetitive spawnings in the same precise locations occur and these are further evidence that some herring, for at least short periods, home to nearly the exact spawning site used by herring in previous years. The explanation offered here for this behaviour is that these intermittent spawnings occurring over periods of several consecutive years represent distinct but transitory or ephemeral stocks that do not become established for long terms. The short-term stocks represent colonizing groups that attempt to occupy new or unused spawning habitat but which are not successful at sustained habitation of the area. The explanation for failure is conjectural but it could represent periodic changes in the oceanographic conditions that in some years results in conditions favourable to larval retention and favourable production cycles, but at other times become unstable for successful herring rearing. Such habitat would then become marginal for sustained herring production but may be periodically reoccuppied and recolonized by groups of herring that split off from the main schools in search of new habitat. Such transitory or colonizing behaviour may be integral to herring biology. For instance, the predisposition to colonize new habitat was necessary for the post-glacial expansion of herring following glacial recession; it is also commonly observed in other clupeids, particularly the colonizing alewife in the Great Lakes. Colonizing fish could account for the "strays" observed during the herring tagging programs of previous years.

There are indications that new spawning habitats may be colonized more often during certain years. For instance, for 1957 to 1959 a number of new locations were used (colonized?) for the first time within the southern Strait of Georgia: (1) Jervis Inlet; (2) the head of Howe Sound and other locations on the Mainland side of the northern Strait of Georgia. Perhaps it was the unusually warm conditions associated with the 1958 El Niño which caused some herring to re-establish in new areas. In each of these locations, herring spawning persisted for a number of years followed by periods of years with no spawning.

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A multivariate approach to describe Pacific herring stocks from size at age and age structure information

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Pacific herring stocks have been examined with a variety of commonly used procedures in an attempt to identify genetically discrete units for stock assessment and management purposes. The early workers used morphometric and meristic characters to identify the major migratory and resident herring populations. The general groupings were subsequently extended and, to some extent, verified on the basis of many years of belly tagging results. The stock structure which was used for setting quotas, during the period of the reduction fishery ending in 1968, assumed the existence of approximately 8 separate migratory populations. They are found to spawn in the lower east coast of the Queen Charlotte Islands, the northern mainland coast, the upper central mainland coast and the lower central mainland coast, the middle east coast of Vancouver Island, and the northwest coast of Vancouver Island.

The advent of the roe fishery required the reevaluation of the stock concept for Pacific herring and 35 management units which represented more or less discrete aggregations of spawning areas were identified for management requirements. More recently electrophoretic studies have shown that Pacific herring of the northeast Pacific are not well differentiated genetically and so may be considered as one panmictic population for management purposes. Consequently, depending on the criteria for stock discreteness, a variety of stock units can be identified.

The factors which affect stock production and biomass most directly are growth, reproduction, and mortality which are reflected in length and weight at age and age composition. Therefore the stock concept adopted in this study is based on the notion that discrete stock production units should be identifiable on the basis of significant segregation. The statistical approaches that have been used in this connection are clustering, ordination, and discriminant analysis.

Average linkage and Ward's clustering analysis of the raw data, of the principal components, and of the canonical variates was used to attempt to describe the number of clusters in the data sets and the geographical origin of the samples in each cluster. In addition, principal components and canonical variates were plotted and discriminant functions calculated and percentage classification success determined for each area. Most extensive and complete coverage of the potentially discrete stock production units was available from three years (1975, 1980, and 1981) of spawning ground samples. The average length, weight, and proportion of fish at age was calculated for each sample. It was found that the most extensive information was available for ages 3-6 so only samples with complete data for these ages were used in the analysis.

The areas examined included Rennell Sound, Louscoone Inlet, Skincuttle Inlet, Juan Perez Sound, and Cumshewa/Skidegate in the Queen Charlotte Islands. The north coast included Chatham Sound, Porcher Island, and Portland Inlet while the central coast included Kitasu Bay, Milbanke Sound, Queen's Sound, Kwakshua Channel, and the mainland inlets. In Georgia Strait, the Johnstone Strait fish, Lambert Channel, Powell River, Qualicum to Nanoose Bay, and Area 17 and 18 fish were examined as separate groups. On the west coast of Vancouver Island, Barkley Sound, Clayoquot Sound, Nootka Sound, Nuchatlitz Inlet, Kyuquot Sound, and Quatsino Sound were examined as potential stock units.

In general, the results from clustering were ambiguous and did not appear to cluster the samples accurately in most instances. Principal components and canonical variate plots indicated the clearest distinction among various areas but results for all areas were not always consistent among years. Results suggest that Rennell Sound, Louscoone Inlet and the three areas on the east coast of the Queen Charlotte Islands represent three separate groups. On the north coast the three groups examined suggest three discrete units. In the central coast the mainland inlet stocks fall out by themselves. The Kitasu Bay and Milbanke Sound fish group together as do the Queen's Sound and Kwakshua Channel fish. In the south the Johnstone Strait fish are separate from the other areas but more similar to the Powell River fish which differ from the other three areas which cannot be separated from one another. On the west side of Vancouver Island, Barkley Sound and Clayoquot Sound represent one group, Nootka Sound, Nuchatlitz and Kyquot Sound, and Quatsino Sound additional discrete units.

Stock production units identified by this approach are similar to but more numerous than units suggested by the traditional morphometric and tagging results. From a management perspective it is suggested that we should attempt to manage the fisheries on the basis of the smaller unit stocks identified here to avoid overharvesting and perhaps eliminating the least productive components of the large migratory groups which appear to have significantly different production characteristics. Herring stocks in British Columbia have not recovered to the levels evident during the reduction fishery period in some areas, which suggests that the unrestricted fishing during this time, when the vulnerability of the smaller and less productive resident stock was increased, eliminated many of them. A conservative notion of stock structure would imply that we manage on the basis of more stock units than has traditionally been acceptable. Because of the large data requirements of many analytical techniques the tendency has been to assess and manage an amalgam of production units which may eventually lead to the elimination of the least productive components in each area.

Scale analysis to discriminate herring stocks

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INTRODUCTION

Since 1976 the Washington Department of Fisheries has conducted a series of acoustic-trawl stock assessment surveys each spring on the southeastern Strait of Georgia herring stock that supported the state's sac-roe fishery from 1973 through 1982. Surveys are run at 2 to 10 day intervals during the spawning period in the stocks' prespawning holding area southeast of Point Roberts. Acoustic and biological data collected are used together with spawning escapement data, to derive run size estimates for use in deciding if and when to open the fishery. Run size is estimated by summing the biomass yet to spawn, as represented by the biomass of mature fish in the holding area, and the biomass already spawned, as represented by the herring biomass equivalent of spawn deposited.

Until 1983, biomass estimates for spent fish in the holding area were not used for stock assessment purposes since there was evidence that those fish represented a mixture of roe herring and non-roe herring stocks in varying proportions. In that year, however, an effort was made to decompose samples of mid-season spent fish into their component stocks to enable an estimate of minimal run size by summing corresponding mature and spent roe herring biomass estimates.

The roe herring stock spawns in April and May, with its peak of spawning tending to occur within a week of May first. Most other stocks inside the Strait of Juan de Fuca spawn in February or March.

In addition to its exceptionally late spawning, the stock is characterised by an exceptionally rapid growth rate. While its mean length at age 1 is smaller than that of other stocks, due to its late spawning, its mean length at age 3 generally equals or exceeds that of other stocks and this faster relative growth tends to continue into the sixth year of life.

The roe herring stock's distinctive pattern of fish growth is reflected in its scales, with the first year's growth zone tending to be smaller, and the second through sixth larger, than those of other stocks. Thus it appeared that the decomposition of the mid-season spent fish into roe herring and non-roe herring components might be achieved in a stock discrimination study based on scale growth characters.

METHODS

Ten surveys were conducted in the roe herring prespawning holding area in 1983. On the basis of length at age and scale characteristics, spent fish sampled during the first survey, on April 11, appeared not to be roe herring. Considering that little spawn had been found on the roe herring spawning grounds prior to that date, it was assumed these fish represented one or more non-roe herring stocks. It was further assumed, on the basis of similarities between these fish and other apparent non-roe herring among the spent fish sampled on subsequent surveys, that all non-roe spent fish sampled during the survey period belonged to the same stock or stock mixture.

Mature fish sampled during the sixth survey, on April 27, in the middle of the run, appeared on the basis of their length at age and scale characteristics, to be essentially pure roe herring. Since no other "inside" stocks were known to spawn significantly that late in the season, these fish were assumed to be representative of the roe herring stock.

Representative subsamples were taken from scale samples of non-roe herring (survey 1 spent fish), roe herring (survey 6 mature fish), and mixed roe and non-roe mid-season spent fish (surveys 5, 6, and 7 spent fish sampled on April 25, 27, and 29, respectively). Annual growth zone widths were determined for each scale by measuring from its center of growth to successive annuli in the scale's 60 degree anterior sector. Frequency distributions of the ratios of selected zone widths to one another were plotted for roe herring and non-roe herring (Fig. 1), and the ratio of the first zone to the second, designated R1T02, was selected as the scale character most suitable for decomposing mixed stock samples. The roe herring and non-roe herring R1T02 distributions were then used in making least squares estimates (Clark 1981) of stock composition from the R1T02 distributions for spent (maturity stages 7 and 8), recently spent (maturity stage 7), and recovering spent (maturity stage 8) mid-season fish samples (Fig. 2).

RESULTS AND DISCUSSION

The estimated percentages of roe herring and non-roe herring in the mid-season spent fish samples are presented in Table 1. The 40% percent roe herring estimate for all spent fish is within the range of prior best guesses based on lab and field observations. The 14% roe herring estimate for recovering spent fish also appears reasonable, considering that spawning had been going on for more than two weeks before the samples were collected. The 42% non-roe herring estimate for recently spent fish, however, seems unrealistically high considering the lack of evidence for significant non-roe herring spawning occurring in April. It is likely that this high percentage of non-roe herring is a result of the misclassification of a substantial portion of the recovering spent fish as recently spents due to poor sample preservation and/or misinterpretations of, or ambiguities in, the maturity stage classification criteria.

ACKNOWLEDGMENTS

I would like to thank Patrick E. McAllister for his general assistance in conducting this study, and William G. Clark for his helpful counsel and his work in decomposing the mixed stock samples.

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Table 1. Estimated percentages of roe herring and non-roe herring among 1983 mid-season (survey 5, 6, and 7) spent fish. (Standard deviation approximated 10% in all cases.)

Category	% roe herring	% non-roe herring
Spent (maturity stages 7 & 8)	40.3	59.7
Recently spent (maturity stage 7)	57.6	42.4
Recovering spent (maturity stage 8)	13.9	86.1

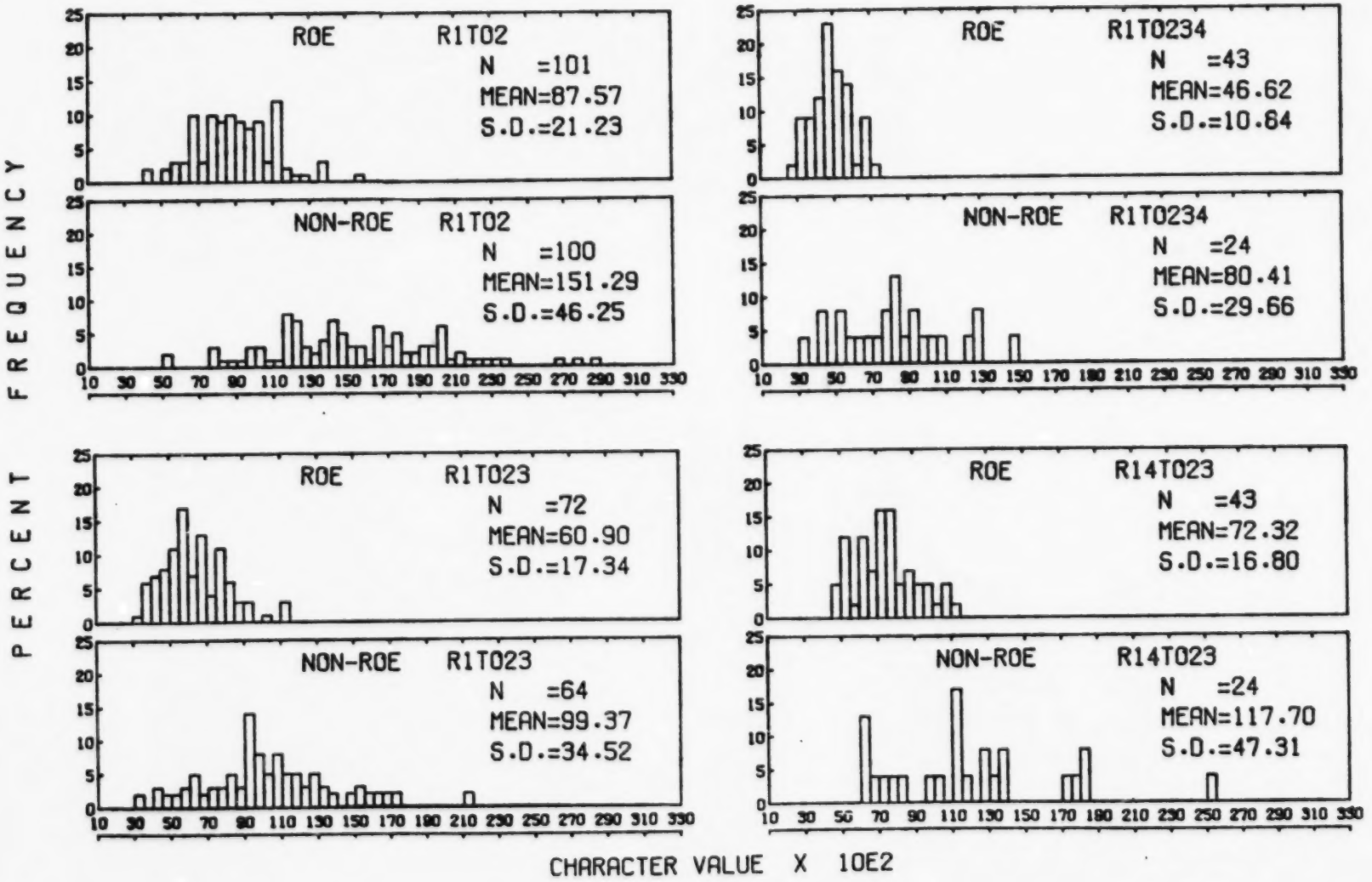

Fig. 1. Scale character distributions for S.E. Strait of Georgia "roe herring" and "non-roe herring" stocks. April 1983.

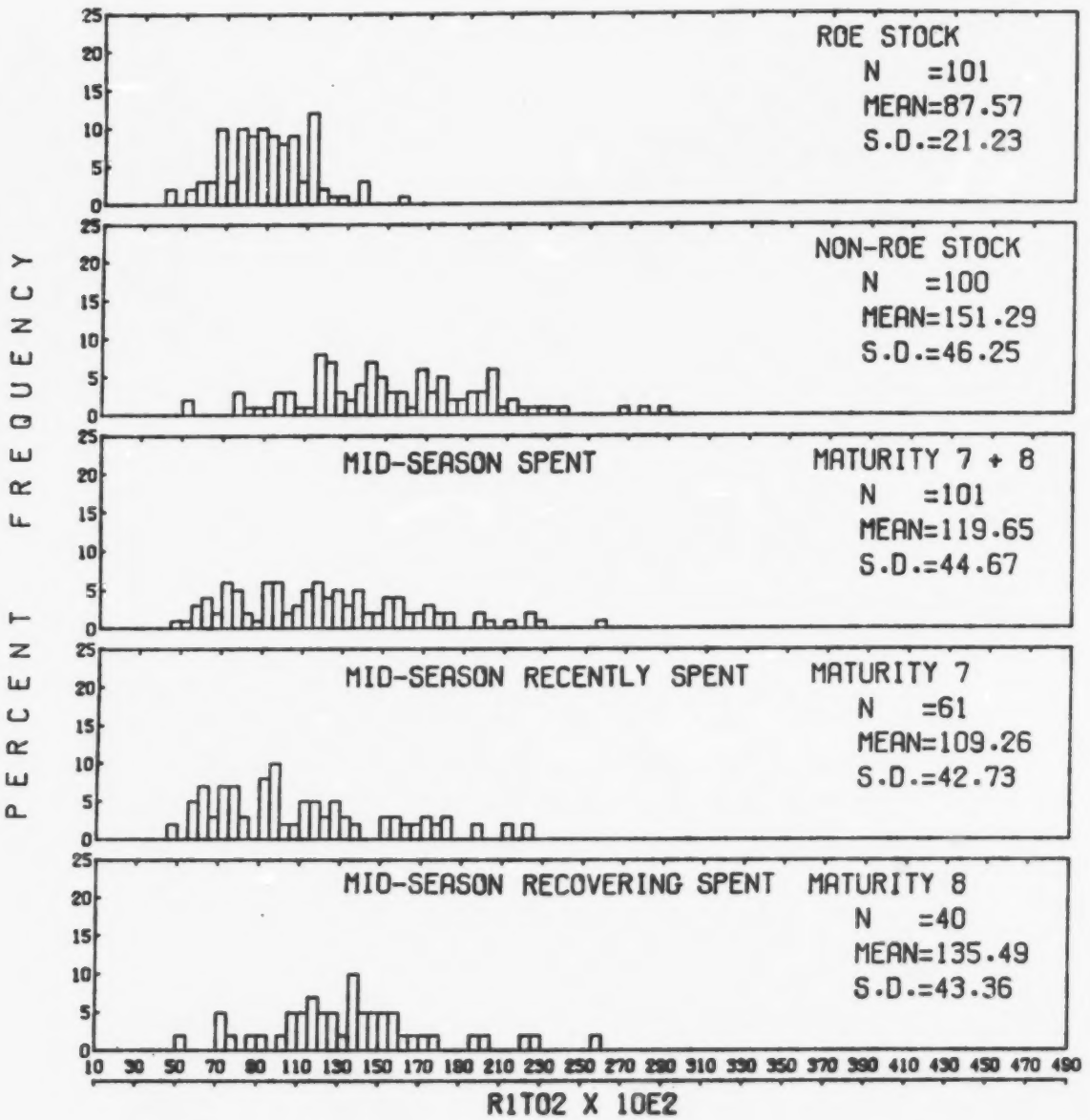

Fig. 2. R1T02 distributions for "roe herring" and "non-roe herring" stocks, and for spent, recently spent, and recovering spent fish in mid-season samples from surveys 5, 6 and 7 (April 25, 27 and 29, 1983, respectively).

Tagging of Washington herring, 1936-1984

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The Washington Department of Fisheries has been tagging herring since 1936, with major tagging periods during the 1950s, and early 1980s. The objective has always been to use tagging to delineate herring populations, and to determine their migratory patterns. The results have provided insights into herring migration and stock mixing, but have not provided the final delineation of specific herring populations.

In the early days, internal metal tags were the favored tag. Canadian researchers including Hart, Tester, Stevenson, and Taylor developed the tagging technology used both in Canada and Washington. During the tagging, an incision was made into the abdominal cavity and the tag inserted. The incision was not closed in any way. Initial mortality may have been quite high, however a systematic study on tag related mortality was never done in Washington. During the years when tagging occurred, there were various herring fisheries such as the reduction fishery, and to provide bait to commercial and recreational fisheries. Tags could most easily be recovered from the herring reduction fishery. Herring were cooked down to a meal product, and oil. As part of the industrial processing, various techniques could be used to separate tagged from untagged fish, or to magnetically collect the metal tag from the meal line. Identifying codes on the tags allowed researchers to correlate recovered tags with the release site.

Since 1980, the herring tag favored by both Canada and Washington has been the external anchor tag. This tag has been constructed with a vinyl tube glued to a monofilament T-shaped anchor. The tag was inserted into the musculature immediately below the dorsal fin. Various tag related mortality studies have been conducted using this tag. The initial mortality was generally quite low, however the long term effects are less well understood. Recovery of these tags could only be visual. This has been a serious factor in the low recovery rate.

RESULTS

Internal Tags

Three herring populations were tagged in the Puget Sound area during the 1950s. A total of 55,149 herring were tagged. These taggings were done primarily during the winter and spring, presumably on spawning fish. Tagged fish were released at Quilcene on Hood Canal, Holmes Harbor on Whidbey Island, and at Brownsville-Miller Bay in central Puget Sound. All three populations had fish returned from their tag release sites some years after tagging. Holmes Harbor had two fish return after five years at liberty. All three

populations had fish returned from the Canadian reduction fishery which occurred during late fall in the southeast Vancouver Island (SEVI) area. Fish were also returned during the summer from Swiftsure Bank, during the fall off Victoria, and during the winter of 1956 from Deepwater Bay at the south end of Johnstone Strait. Only one fish, from the Miller Bay group, was ever returned from the U.S. reduction fishery. This fishery began in 1957, some years after the tagging of Puget Sound fish.

During the mid-1950s, 11,808 herring were tagged in November in various locations throughout the San Juan Islands. November was chosen in order to intercept herring on their way to the Canadian reduction fishing grounds of SEVI. All recoveries occurred in the Canadian reduction fishery in this area. Most recoveries occurred within a few months of release. Apparently, herring supporting this Canadian reduction fishery took a swing through the San Juan Islands on their way to Canada. The U.S. reduction fishery began in the San Juans on these migratory fish in the fall of 1957, but never recovered any tags released in the San Juans.

Bellingham Bay became the major fishing area of the U.S. reduction fishery during the first season, 1957-58. During February, 1958, 6115 tags were released in Bellingham Bay. The majority of recoveries in subsequent seasons occurred from the U.S. reduction fishery in Bellingham Bay and the western San Juan Islands. Fewer recoveries occurred in the Canadian reduction fisheries in SEVI, and Barkley Sound. Herring were also tagged in March, 1958 along the east shore of Point Roberts (4197). The majority of recoveries occurred the following fall and winter in Bellingham Bay. Recoveries also occurred during summer and fall in the Canadian SEVI area, during fall in the western San Juan Islands, and during the winter in Barkley Sound and Nootka Sound.

During the mid-1960s, U.S. fishermen noted that in September and October, a large body of herring appeared along the West Beach area of Whidbey Island. This is at the extreme eastern end of the Strait of Juan de Fuca. These fish were gone by November. In early October, 1965, 6219 herring were tagged here. All recoveries were from U.S. reduction fisheries that same fall-winter season, 1965-66. Recoveries were split evenly between Bellingham Bay, the western San Juan Islands, and Pt. Roberts. No recoveries came from Canadian reduction fisheries even though there were large returns of Canadian tags from those fisheries that season.

Canadian tagged herring have been taken very rarely in U.S. fisheries. In the summer of 1965, 12,000 tags were released on Swiftsure Bank, B.C. During subsequent fishing seasons, 8 were returned from U.S. fisheries. Two were from the western San Juan Islands, 3 from Pt. Roberts, 1 from Bellingham Bay, and 2 from one of these areas. Canadian recoveries during the same period were 941 from Swiftsure, 2 from Upper west coast Vancouver Island, 63 from the lower west coast Vancouver Island, and 157 from lower east coast Vancouver Island (SEVI).

Herring tagging in Washington took a rest until 1980.

External Tags

The major herring population in Washington is found along the eastern Strait of Georgia from Pt. Roberts to Lummi Island. The center of the spawning distribution is at Pt. Whitehorn. During late April-early May of 1981 and 1982, 18,400 herring were tagged. The tag and techniques used had been developed by Canadian researchers. One tagged fish returned to the site of tagging exactly one year later. In addition, one fish was returned from a roe fishery in Barkley Sound, and one from offshore of Barkley Sound during the summer. Three were returned from the SEVI area from November through March in subsequent seasons. During the 1982 tagging, many well recovered spent fish were mixed in with maturing fish. Some of these spent fish got tagged. From this seasons tagging, two fish were returned from successive years roe fisheries in Lambert Channel.

Canadian researchers were also tagging during this time. There have been three recoveries of Canadian tags from U.S. herring fisheries. These fish were tagged in the SEVI area from November through March. The three recoveries were made in early May, from the eastern Strait of Georgia, Cherry Pt. to Birch Pt. It would appear that at least some of this late spawning U.S. stock spends some of the winter and spring in the channels of the Canadian Gulf Islands-the SEVI. These fish were subjected to a fishery during the winter in Canada, and during the spring to a roe fishery in U.S. waters.

Herring are no longer being tagged in Washington, and there are no plans to resume tagging in the near future. If tagging were to be resumed, the tag to be used may well be the coded wire tag (CWT). Preliminary test results both in the U.S. and Canada are quite promising, as are the field applications currently being used in the North Sea. The major problem, besides funding, is to rejuvenate herring fisheries and keep them viable long enough to get a reasonable number of returns. Sounds like a challenging problem.

WORKSHOP SUMMARY

Workshop Summary

Vidar Vespestad and Max Stocker
(transcribed by C. W. Haegele from a recording of the oral presentation)

The theme of this workshop appears to have been "Where have all the herring gone? ". Hopefully the theme for the next herring workshop will not be "Resume writing for ex-herring biologists ". When some of us became involved with herring about eight years ago, everyone was riding a crest and a lot of money was being earned by fishermen. Today the situation is very different and fishermen have felt the effects of declining catches and prices. The situation three years from now is likely to be again very different, with a whole generation of herring having passed through the fishery. Perhaps things will not look so bleak then and hopefully they will not be worse. In a workshop then we are likely to have a lot of the same topics and some of the same questions, but we will likely be looking at everything somewhat differently. Perhaps our friend El, El Niño that is, will again be there. He certainly has been present recently, up and down the coast. We have heard of him in San Francisco Bay, causing young fish to grow slower and older fish to grow faster; in British Columbia, where he has adversely affected recruitment; and in Alaska, where he has done the reverse. The overall effects of warm water are not yet fully understood.

In fisheries management there has been a variety of structure implemented on the coast. However, basically, everyone is focusing in the same direction, basing fisheries on harvest rates and managing for a roe fishery. The British Columbia structure for managing fisheries seems to work well because it gets everyone involved: researchers, managers, and users of the resource. The important aspect appears to be communication. This is also true for Alaska. The other aspect that is really important in fisheries management is to leave a paper trail that documents management decisions and the rationale for these decisions. Quite frequently, in the past, management strategies have been implemented based on a historical basis, but the rationale for the strategy has become obscure because it was not documented and the initiator has departed the scene. The documentation of management strategies is a worthwhile take-home message for all of us. If decisions are well documented then it is much easier for someone who has not been previously involved to step in and manage stocks and fisheries. With documentation it is much easier to reconstruct some time down the road what occurred. Especially those decisions based on in-season estimates, which would not be otherwise documented, are relevant in reconstructing the productivity of some stocks.

The institutional arrangements for conducting fisheries are somewhat different for jurisdictions. In San Francisco Bay the platoon approach is used for gillnet fishery openings and is workable because the season is protracted over several weeks. This approach certainly would not work in areas where roe fisheries could harvest the quota in a few hours. The management strategy that none of us would like to employ, having no fisheries, has unfortunately been necessary in Washington state. In British Columbia, the reduction in quotas has resulted in implementing additional structure and managers have had to search for innovations that would allow the equitable

distribution of a smaller pie to user groups. In Alaska the fisheries are more open with all applicants for a license being allowed to participate in some areas, and fishing in other areas being restricted by some criterion. In the Arctic the potential of a roe fishery is being evaluated. Alternatives, such as impoundments for roe harvesting, have also been studied to take the pressure off stocks that are fished with the more traditional gear and methods.

Presentations on the life history and recruitment were quite diverse. What appears to be happening is low recruitment and changes in mortality which are adversely affecting the surviving biomass. By and large, the trend seems to be for declining biomass. The exception appears to be the Bering Sea stocks, but there the reliance on just one method of assessment (aerial surveys of fish schools) makes stock estimates somewhat more tenuous. The focus in problems of recruitment are presently on the early life history stage. Predation on larvae, transport of larvae, and the effects of pollution on larvae and eggs certainly all appear to contribute to the recruitment process. These are all difficult to quantify but there has been encouraging progress in the last several years in attempts to quantify survival in the early life history stage. The consensus seems to be that it is necessary for stocks to recover out of the lower left-hand limb of the functional response curve so that predation on eggs and larvae cannot drastically affect recruitment. If predators can be saturated with eggs and larvae, then there is a better chance for higher survival of the survivors. Certainly there seems to be depensatory (density dependent) mortality that is difficult to quantify. Changes in annual mortality are difficult to deal with but perhaps that is the direction in which we are heading and it will be necessary to re-parameratize our models to deal with annual changes in mortality to determine survival. The best approach is probably not to look at all the various factors in isolation but to take a global approach and build it into stock reconstruction models. Simultaneous estimation that incorporates all known population parameters should probably be done and in that way determine whether model fits improve.

Presently we are working with several definitions of stocks. Each technique seems to result in different stock concepts. The important thing is to be able to separate stocks with different productivity, so they can be managed accordingly. What should be done is a synthesis of all available stock concept information into a stock hypothesis and testing this hypothesis with a comprehensive tagging program. We should be prepared to test workable hypothesis with tagging once recruitment turns around and this becomes feasible with larger and more diversified fisheries.